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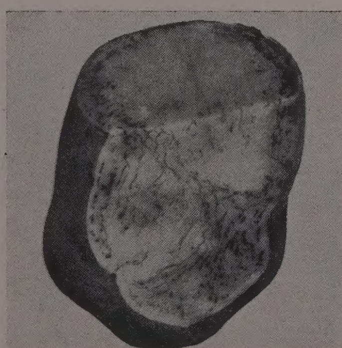
The Effect of Fertilizer Practice Including the Use of Minor Elements on Stem-end Browning, Net Necrosis, and Spread of Leafroll Virus in the Green Mountain Variety of Potato

In Cooperation with the Bureau of Plant Industry, United States Department of Agriculture

Stem-end Browning



Net Necrosis

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BULLETIN 447

The Effect of Fertilizer Practice Including the Use of Minor Elements on Stem-End Browning, Net Necrosis, and Spread of Leafroll Virus in the Green Mountain Variety of Potato

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INTRODUCTION

In Maine and in some other areas the Green Mountain variety of potato is subject to stem-end browning and net necrosis. Both of these diseases are distinct types of internal discoloration that develops largely in storage. The cause of stem-end browning is still uncertain although recent experiments indicate that the disease is related to an unknown virus (15, 16). Stem-end browning appears in the tuber as dark brown streaks with adjacent tissue lighter brown in color and quite watery in appearance. The discolored area begins at the stem scar and rarely extends more than ½ inch into the tuber (Figure 1). Both the xylem and the phloem may be necrotic (10). Net necrosis (Figure 2) is a frequent symptom of current season infection with leafroll virus (17). It differs in appearance from stem-end browning in that the discoloration may penetrate deeper into the tuber, the strands are not continuous and occur in a greater number of concentric zones. Net necrosis affects the phloem tissue not the xylem (10).

Of the other varieties commonly grown in Maine, only the Irish Cobbler is appreciably subject to these diseases. Among the newer varieties Mohawk is subject to net necrosis. In some seasons these abnormalities are so prevalent as to threaten the continued production of these varieties, particularly the Green Mountain. Because of the popularity of the Green Mountain and its excellent

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eating quality, an extensive program has been under way at this Station to examine all possible methods of controlling these two defects.

At the beginning of this work the cause of stem-end browning was not known and it was considered possible that it could be caused by certain cultural practices, especially those leading to a deficiency or toxicity of some element or elements. The introduc-

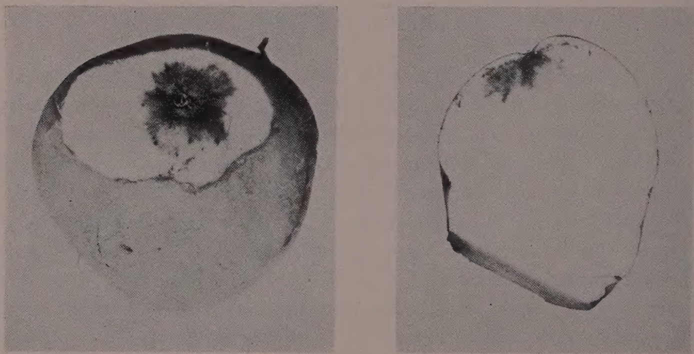

FIGURE 1. Stem-end Browning in Green Mountain Tubers. (Photograph by M. T. Hilborn)

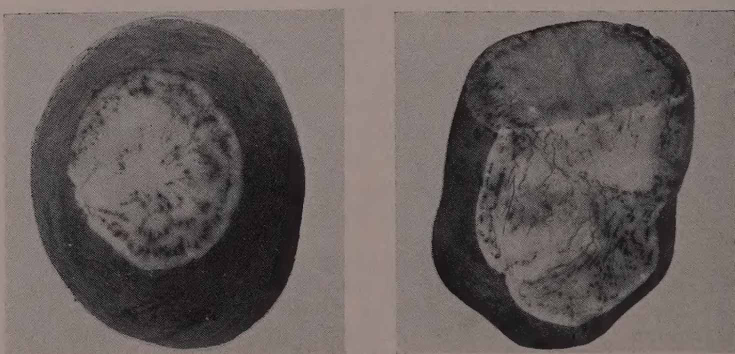

FIGURE 2. Net Necrosis in a Green Mountain Tuber. (Photograph by M. T. Hilborn)

tion of the virus relationship still did not preclude a consideration of the effect of cultural practices on the disease. The crop produced on some fields from a seed lot where all tubers are equally predisposed to the disease will develop more stem-end browning than that grown on other fields; all tubers of a single hill do not show the disease; and the amount of stem-end browning may vary from year to year. Hence, there are other factors that determine whether or not a susceptible tuber will develop stem-end browning. The same situation holds for net necrosis, as all tubers that contract leafroll virus during the growing season do not develop net necrosis. A suggestion that nutrition may play a role in the development of net necrosis and stem-end browning has been made by Dunklee and Midgley (6).

The purpose of this bulletin is to present data indicating the effect of rate of fertilizer application, fertilizer ratio, and type of fertilizer ingredients on the development of net necrosis and stem-end browning in the stored crop. Data on the effect of minor elements are also included.

EXPERIMENTAL

Many of the data were obtained on potatoes grown on a series of permanent soil fertility plots located on Aroostook Farm, near Presque Isle, in Aroostook County, Maine. A complete description of these plots has been given by Chucka, Hawkins, and Brown (4). A brief description will suffice to aid in interpreting the data to be presented. The plots are located on Caribou loam, the predominating soil type in the potato growing area of Aroostook County, Maine. A field of approximately five acres was divided into four equal areas and each of these areas subdivided into 35 plots. The entire series of plots was cropped without fertilizer from 1919 to 1926 inclusive. Since 1927 three sections have been utilized as a 3-year rotation of oats-clover-potatoes so planted that one section was planted to potatoes each year. Thirty plots of the fourth section were established as a 2-year rotation of potatoes-green manure crop. The remaining 5 plots were cropped continuously with potatoes.

The standard mixture applied at 2000 pounds per acre was a 4-8-7 during 1927 to 1939, inclusive, and a 4-8-8 since 1939. Un-

less otherwise stated, the nitrogen was derived: 3/8 from nitrate of soda, 3/8 from sulfate of ammonia, and 1/4 from fish meal. The phosphoric acid was derived from ordinary superphosphate and the potash from muriate of potash. Seven of the plots in the 3-year rotation were fertilized with chemically pure salts containing no nutrient elements other than N, P, and K. In this case, a mixture was prepared and applied in amounts equivalent in N, P, and K to the standard check application. All plots, except those fertilized with chemically pure salts, those which received manure, and those 1/2 plots previously limed, were treated with 1000 pounds per acre of magnesium limestone in 1940.

Other fertilizer experiments with potatoes were conducted on other fields on Aroostook Farm and on privately owned farms in Aroostook County. Most of them were on Caribou loam. The Green Mountain variety was used exclusively and, unless otherwise stated, a strain quite subject to stem-end browning was used.

Stem-end browning was differentiated from net necrosis by the objective method described by Folsom and Rich (10). Unless otherwise specifically stated, all references to the amount or severity of disease refer to the percentage of examined tubers showing the disease in question. In most cases, tubers with stem-end browning were not rated as to severity of the disease. Since some tubers showing the disease show only a slight amount of discoloration, it was felt that data would be of more practical value if counts were taken on those where the disease had developed to a degree regarded as objectionable by inspectors and housewives. Consequently, in 1944 such a classification was attempted in some cases, with "severe" stem-end browning arbitrarily defined as that penetrating the tuber 1/4 inch or more.

All tuber samples were stored at 50° F. for 100 days or longer from date of harvest prior to examination. This storage period was used in view of the results of Folsom and associates (7, 8, 9, 18) indicating that both net necrosis and stem-end browning reach maximum development only under these conditions. It was assumed that in a given field or section, all replicates were equally exposed to leafroll infection. If a given treatment failed to influence the amount of net necrosis, it was assumed that neither the susceptibility to leafroll virus nor the net necrosis/leafroll ratio[2] was

[2] Percentage of tubers with leafroll virus that develop net necrosis.

affected. In those cases where there was an appreciable increase or decrease in the percentage of tubers developing net necrosis the tubers were replanted the following season and leafroll counts taken.

In all experiments, the seed used was low in leafroll. Counts were taken in some instances but they were so uniformly low and the diseased plants so evenly distributed that they were not entered in the calculations. The figures in the tables are, therefore, total leafroll in the crop and would differ from "leafroll increase" by only a few tenths of one per cent.

Except for 1944, the figures on yield on the permanent plots are the averages of 6 single rows, each 4 rods long. In 1944 only 3 rows were used. On certain plots that were further subdivided, the rows were only 2 rods long. The figures on stem-end browning, net necrosis, and leafroll are the averages of 6 one-bushel samples, each taken from a single row, except that in 1944 only 3 samples were taken. In the case of other plots, the plot size and number of samples are indicated in the tables.

RATE OF FERTILIZER APPLICATION

Stem-end Browning. Data on samples from the permanent plot are given in Table 1. For the 3-year rotation in a given season it is obvious that at the lower rates of application there was positive correlation between the amount of fertilizer applied and the incidence of stem-end browning in the stored crop. In 1941 and 1943, the same correlation held for the higher rates of application. In the other two years, however, addition of fertilizer above 2000 pounds per acre resulted in a progressive decrease in the number of tubers which developed stem-end browning. It may be significant that in both of these years uniformly low yields resulted from drought during the growing season. The inhibiting effect of excess fertilizer was even more marked in the plots planted to potatoes every year. In fact, only in 1943 did the plot receiving 2500 pounds produce tubers with more stem-end browning than did that receiving 2000 pounds.

When varying amounts of a complete fertilizer were applied to other fields the results were inconsistent (Table 2). In 1941 the larger amounts of fertilizer resulted in a greater incidence of stem-end browning in the crop. In 1942 no consistent effect was

TABLE 1

The Effect of Rate of Fertilizer Application on Stem-end Browning
Permanent Plots

Rotation and treatment[1] per acre	Yield per acre					Stem-end browning					
	1941	1942	1943	1944	Av.	1941	1942	1943	1944		Av.
									Sev.	Total	
	Bu.	Bu.	Bu.	Bu.	Bu.	%	%	%	%	%	%
3-year Rotation											
No fertilizer	158	92	178	136	141	1.6	3.1	0.6	0.0	0.9	1.6
1500 lbs.	434	360	413	382	397	9.6	26.0	13.1	9.6	24.1	18.2
2000 lbs.	476	361	417	380	409	21.4	36.8	36.7	3.9	26.3	30.3
2000 lbs.[2]	456	375	434	385	413	16.1	35.0	26.5	5.2	25.2	25.7
2500 lbs.	483	385	435	393	425	24.8	33.7	52.8	7.0	23.8	33.8
3000 lbs.	505	407	435	399	437	29.8	30.7	52.1	6.9	18.5	32.8
Continuous Cropping											
2000 lbs.	442	387	511	361	425	21.4	52.7	39.6	27.0	49.1	40.7
2500 lbs.	505	431	507	406	462	20.6	44.6	58.2	11.1	16.0	34.9

[1] A standard 4-8-8 mixture used in each case.
[2] See footnote 2, Table 4.

apparent. On a field not previously fertilized (Table 12) no marked correlation between rate of application and stem-end browning was obtained. In fact, the crop from the plot receiving a 3500-pound application of one 4-8-8 mixture developed no more disease than did that from the unfertilized plot. It is apparent that the past history of a given plot has just as great or a greater effect on the amount of stem-end browning in the crop as does the current season application of fertilizer.

TABLE 2

The Effect of Rate of Fertilizer Application on Net Necrosis and Stem-end Browning
Aroostook Farm

Year	Rate[1] per acre	Stem-end browning[2]	Net necrosis[2]	Yield[2] per acre
	lbs.	%	%	Bu.
1941	1000	39.8	3.1	378
	1250	51.6	5.5	397
	1500	54.6	9.3	371
1942	1000	55.3	19.2	460
	1250	53.3	21.4	465
	1500	57.3	18.2	447

[1] An 8-16-20 mixture was used in each case.
[2] Average of 6 to 9 one-bushel samples.

Net Necrosis and the Spread of Leafroll. The amount of fertilizer applied also had an effect on the amount of net necrosis developed in storage (Table 3). In practically every case increased amounts of fertilizer resulted in increased amounts of net necrosis. The question naturally arose as to whether the variation in amount of net necrosis developed in the crop from the different plots was due to an effect on the spread of leafroll virus or on the net necrosis/leafroll ratio. Consequently, the tubers from these plots were replanted the following season and field readings taken on the leafroll content. These data, also listed in Table 3, indicate that the effect was on both the spread of leafroll and on the ratio. With few exceptions, increasing the rate of fertilizer application resulted in an increase in leafroll spread and in an increase in the net necrosis/leafroll ratio.

TABLE 3

The Effect of Rate of Fertilizer Application on Net Necrosis and the Spread of Leafroll
Permanent Plots—3-year Rotation

Treatment[1]	Net necrosis[2]					Leafroll				(Net necrosis/Leafroll) X 100			
	1941	1942	1943	1944	Av.	1941	1942	1943	1944	1941	1942	1943	1944
	%	%	%	%	%	%	%	%	%	%	%	%	%
No fertilizer	1.6	3.0	0.4	16.2	5.3	11.5	21.8	2.5	—	13.9	13.8	16.0	—
1500 lbs.	4.5	11.8	2.7	17.0	9.0	17.7	26.9	—	35.7	25.4	43.9	—	47.6
2000 lbs.	9.7	14.7	5.0	35.3	16.2	28.8	32.3	9.1	65.4	33.7	45.5	54.9	54.0
2500 lbs.	13.6	22.0	4.9	42.0	20.6	—	42.3	—	62.4	—	52.0	—	67.3
3000 lbs.	17.7	24.7	11.5	35.1	22.3	40.8	42.0	18.3	69.0	43.4	58.8	62.8	50.9

[1] Amount of 4-8-8 applied per acre.

On other fields, rate of fertilizer application had no effect on the amount of net necrosis in 1942 but did have some effect in 1941 (Table 2). On a field not previously fertilized, the amount of net necrosis was independent of the amount of fertilizer applied (Table 13). It appears that the effect of a given treatment is most noticeable on plots where that treatment has been applied over a period of years.

NITROGEN

Stem-end Browning. The amount of nitrogen added in mixtures containing ample quantities of phosphorus and potash had

little or no effect on the amount of stem-end browning in the crop, except that the use of a 0-8-8 mixture resulted in a smaller percentage of diseased tubers (Table 4). Increasing the proportion of nitrogen above a 2-8-8 mixture did not influence the incidence of disease. In the 3-year rotation, the source of nitrogen had no consistent effect on stem-end browning content of the crop except in the case of cyanamid. The reduction resulting from the use of this compound may possibly have been due to the fact that the plants on this plot were not normal in growth and produced a smaller yield.

TABLE 4

The Effect of Different Proportions of Nitrogen in Potato Fertilizer and Source of Nitrogen on Stem-end Browning

Permanent Plots

Rotation	Treatment[1]	Yield per acre					Stem-end browning					
		1941	1942	1943	1944	Av.[5]	1941	1942	1943	1944 Sev.	1944 Total	Av.[5]
		Bu.	Bu.	Bu.	Bu.	Bu.	%	%	%	%	%	%
3-year	0-8-8	356	268	403	330	340	12.7	15.9	13.9	2.4	11.5	13.5
	2-8-8	430	397	[illegible]	394	422	12.9	32.9	24.1	12.0	36.4	26.6
	4-8-8	476	361	[illegible]	380	409	21.4	36.8	36.7	3.9	26.3	30.3
	4-8-8[2]	456	375	434	385	413	15.1	35.0	26.5	5.2	26.2	25.7
	6-8-8	502	[illegible]	[illegible]	391	429	13.0	31.6	38.2	4.4	24.7	26.9
	Sodium nitrate	[illegible]	[illegible]	[illegible]		415	15.7	38.0	24.4			26.0
	Ammonium sulfate	439	378	[illegible]		419	14.6	36.6	27.9			[illegible]
	Urea	456	371	441		423	12.1	30.4	26.0			22.8
	Fish meal	459	363	424		415	14.5	34.6	34.1			27.7
	Cyanamid	397	299	383		360	12.6	25.7	13.1			17.1
	½-½-0[3]	492	397			—	13.2	25.0	—			—
	⅜-⅜-¼[3]	476	361	417		418	21.4	36.8	36.7			31.6
	¼-¼-½[3]	455	409	—		—	12.8	34.8	—			
2-year	Sodium nitrate	479	392	406			15.6	42.0	30.8			
	Ammonium sulfate	426	403[6]	515			7.3	32.0[6]	18.4			
	Ammonium sulfate (limed)[4]	[illegible]		401			17.4	—	18.7			
	Ammonium chloride	421					20.2					
	Ammonium chloride (limed)[4]	388					31.3					

[1] The first four treatments consisted of 2000 pounds per acre of the indicated fertilizer mixtures. In the remaining treatments only the source of nitrogen is indicated. The total application was 2000 pounds per acre of a 4-8-8 mixture.

[2] Except for 1944, average of 5, 4-8-8 plots, some of which differed from the foregoing regular 4-8-8 treatment only in a manner known not to affect stem-end browning. In 1944 the results from only two plots were averaged.

[3] The fractions refer to the proportion of the nitrogen supplied by nitrate of soda, sulfate of ammonia and fish meal respectively.

[4] Limed halves received applications of 2000 pounds calcium limestone in each of the following years: 1931, 1933, and 1935.

[5] Three- or 4-year average as indicated by years for which data are given.

[6] Composite sample from limed and unlimed halves.

In 1941 and in 1943, the crop from the plot receiving the nitrogen from the 3/8-3/8-1/4 mixture, or the so-called check plots, was higher in stem-end browning than that from the others. This is difficult to understand, for the plots where sodium nitrate, ammonium sulfate or fish meal was used alone as the source of nitrogen all produced tubers with about the same amount of stem-end browning. The identical treatment (3/8-3/8-1/4) was given to another half plot each year, and in 1941 and 1943 the stem-end browning content of the crop from these plots was similar to that of the crop produced on the sodium nitrate, sulfate of ammonia, and fish meal plots. It would appear, therefore, that the two high readings are anomalous and attributable to soil variation or other environmental conditions. It should be noted that this is the standard check mixture (4-8-8) and that it appears in all tables dealing with the 3-year rotation. Consequently the occurrence of an anomalous reading for this single plot in any one year might lead to erroneous conclusions in any of several comparisons. As the source of nitrogen appears to be without effect on stem-end browning, it appeared desirable to average the figures for all such plots (except the cyanamid plot) with those receiving the regular 4-8-8 mixture and to include such figures in the tables. Consequently the averaged figures in Table 3 and others are obtained from the regular 4-8-8 plot, a half plot receiving the same mixture, and those plots receiving nitrogen from sodium nitrate, ammonium sulfate, and fish meal, respectively. In 1944, figures for the source of nitrogen plots were not obtained, hence the average is derived from the two first named plots.

The data on the 2-year rotation are too few to permit definite conclusions, but there is certainly a tendency for tubers from plots which received ammonium sulfate to develop less stem-end browning than for those from the sodium nitrate plots. Liming the former increased the amount of stem-end browning in 1941 but not in 1942 and 1943. On the other hand the use of ammonium chloride resulted in an increase in the amount of stem-end browning, particularly where lime was applied. This effect is probably due to the chloride as will be shown in a later section.

The discrepancy between results from the 3-year rotation and those from the 2-year rotation is not necessarily surprising. It should be remembered that those plots in the 2-year rotation are planted to potatoes and fertilized every two years in comparison

to every three years for the other rotation. Hence any residual effect of the fertilizer or any depletion of minor elements would be greater in the 2-year rotation.

Net Necrosis. The nitrogen ratio used in the fertilizer had very little effect on the amount of net necrosis in the stored crop (Table 4). The only consistent effect was that low proportions of nitrogen resulted in slightly smaller percentages of tubers which developed net necrosis than did higher proportions. Except for ammonium chloride, the source of nitrogen likewise had no consistent effect on net necrosis development. Although there are only one year's data on the ammonium chloride plots, the large amount of net necrosis that developed in the tubers from such plots is probably significant. The question of the effect of chloride will be discussed later.

TABLE 5

The Effect of Nitrogen Ratio and the Source of Nitrogen on Net Necrosis and the Spread of Leafroll

Permanent Plots

Rotation	Treatment[1]	Net necrosis					Leafroll		(Net necrosis/ leafroll) X 100	
		1941	1942	1943	1944	Av.	1942	1943	1942	1943
		%	%	%	%	%	%	%	%	%
3-year	0-8-8	5.8	8.2	2.7	18.3	8.8	24.8	4.0	33.1	67.5
	2-8-8	6.7	16.7	5.5	23.1	13.0	38.9	9.2	42.9	59.8
	4-8-8	9.7	14.7	5.0	35.3	16.2	32.3	9.1	45.5	54.9
	6-8-8	11.7	24.5	1.8	27.7	16.4	—	5.5		32.7
	Sodium nitrate	6.8	16.5	4.4						
	Ammonium sulfate	12.0	9.2	4.6						
	Urea	7.9	10.6	5.5						
	Fish meal	12.6	16.1	1.7						
	Cyanamid	9.8	14.2	6.0						
	½-½-0[2]	11.0	17.3	—						
	⅜-⅜-¼[2]	9.7	14.7	5.0						
	¼-¼-½[2]	7.6	17.4	—						
2-year	Sodium nitrate	12.2	11	2.9						
	Ammonium sulfate	13.3	16[4]	10.7						
	Ammonium sulfate (limed)[3]	11.3	—	6.6						
	Ammonium chloride	25.7	—	—						
	Ammonium chloride (limed)[3]	29.7	—	—						
	½-½-0[2]	7.3	14	—						
	Delayed N	6.4	11	—						

[1] The first four treatments consisted of 2000 pounds per acre of the indicated fertilizer mixtures. In the remaining treatments only the source of nitrogen is indicated. The total application was 2000 pounds per acre of a 4-8-8 mixture.
[2] The fractions refer to the proportion of the nitrogen supplied by nitrate of soda, sulfate of ammonia, and fish meal respectively.
[3] See footnote 2 in Table 4.
[4] Composite sample from both limed and unlimed halves.

Since the nitrogen ratio or source had little or no effect on net necrosis development, data were not obtained on the spread of leafroll except as indicated in Table 5. Other than a slight reduction in the case of the 0-8-8 application, the proportion of nitrogen in the fertilizer had no consistent effect on either the spread of leafroll or the net necrosis/leafroll ratio in the crop.

PHOSPHORUS RATIO

Stem-end Browning. The proportion of phosphorus (expressed as P_2O_5) in the potato fertilizer had no consistent effect on the amount of stem-end browning in the stored crop (Table 6). The figures for the standard 4-8-8 mixture are higher in 1941 and 1943 than those for the other treatments. These are the same plots mentioned earlier as giving anomalous results and the averaged figures are regarded as more representative of this treatment.

TABLE 6

The Effect of Phosphorus Ratio on Stem-end Browning

Permanent Plots—3-year Rotation

Treatment[1]	Stem-end browning						Yield per acre				
	1941	1942	1943	1944 Sev.	1944 Total	Av.	1941	1942	1943	1944	Av.
	%	%	%	%	%	%	Bu.	Bu.	Bu.	Bu.	Bu.
4-0-8	12.3	29.0	28.2	3.3	15.9	21.4	339	157	333	260	272
4-4-8	11.7	35.9	23.4	8.9	34.7	26.4	476	382	472	361	423
4-8-8	21.4	36.8	36.7	3.9	26.3	30.3	476	361	417	380	409
4-8-8[2]	15.1	35.0	26.5	5.2	23.2	25.7	456	375	434	385	413
4-12-8	16.5	28.9	17.0	6.9	28.8	22.8	482	383	454	397	429

[1] 2000 pounds per acre applied in each case.
[2] See footnote 2 in Table 4.

Net Necrosis and Spread of Leafroll. On the permanent plots the amount of phosphorus applied in mixtures containing constant amounts of nitrogen and potash had a definite effect on the amount of net necrosis that developed in storage (Table 7). In general, the greater the amount of phosphorus applied, the greater the amount of net necrosis developed. The most notable exception was in 1941 when the crop from the plot receiving the 4-0-8 application developed more net necrosis than did that from plots receiv-

ing any of the other treatments. It should be noted that in 1943, a year of light leafroll infestation, and in 1944, a year of exceptionally heavy leafroll infestation, very definite correlation was obtained. The data on leafroll are quite similar. With a few exceptions, increasing the amount of P_2O_5 added resulted in greater leafroll spread. The net necrosis/leafroll ratio showed a greater variation. In 1941 there was an inverse correlation of this ratio with the amount of P_2O_5 applied; in 1943 the correlation was positive; and in the other two years no correlation was apparent. It can be concluded, therefore, that the effect of phosphorus on the amount of net necrosis that develops is almost entirely due to its effect on the spread of leafroll.

TABLE 7

The Effect of Phosphorus Ratio on Net Necrosis and the Spread of Leafroll

Permanent Plots—3-year Rotation

Treatment[1]	Net necrosis					Leafroll					(Net necrosis/Leafroll) X 100				
	1941	1942	1943	1944	Av.	1941	1942	1943	1944	Av.	1941	1942	1943	1944	Av.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
4-0-8	13.5	10.1	1.8	18.6	11.0	22.1	28.5	4.3	39.3	23.6	61.1	35.4	41.9	47.3	46.4
4-4-8	6.5	17.2	3.7	22.0	12.7	12.5	34.4	7.6	34.0	22.1	52.0	50.0	48.7	64.7	53.9
4-8-8	9.7	14.7	5.0	35.3	16.2	28.8	32.3	9.1	65.4	33.9	33.7	45.5	54.9	54.0	47.0
4-12-8	10.9	25.8	8.4	42.1	21.8	31.8	45.0	14.6	68.6	40.0	34.3	57.3	57.5	61.4	52.6

[1] 2000 pounds per acre applied in each case.

The question naturally arose as to whether the tendency of increasingly larger amounts of a complete fertilizer to increase the amount of net necrosis that develops in storage and the extent of leafroll spread was due solely to the amount of phosphorus applied. In Figure 3 data on leafroll and net necrosis from Tables 1 and 7 were plotted as ordinates and the amount of P_2O_5 as abscissas. This makes possible a comparison of the effect of various amounts of P_2O_5 when supplied in a 4-8-8 fertilizer with that of the same amount of P_2O_5 in mixtures with constant proportions of N and K_2O but variable proportions of P_2O_5. A fairly similar pattern was exhibited during each of the four years. At low amounts of P_2O_5, the tubers from plots fertilized with the standard 4-8-8 showed less net necrosis and leafroll than did those from plots fertilized with mixtures having a different N-P-K ratio but which

had the same P_2O_5 content. At high levels of P_2O_5, the reverse situation held true in 1941 and 1943. In the other two years, the N-P-K ratio of the fertilizer did not matter. In either event, the greatest discrepancy occurred where low rates of phosphorus applications were made. It appears that in certain years some other component of the complete fertilizer also may affect the amount of net necrosis and leafroll.

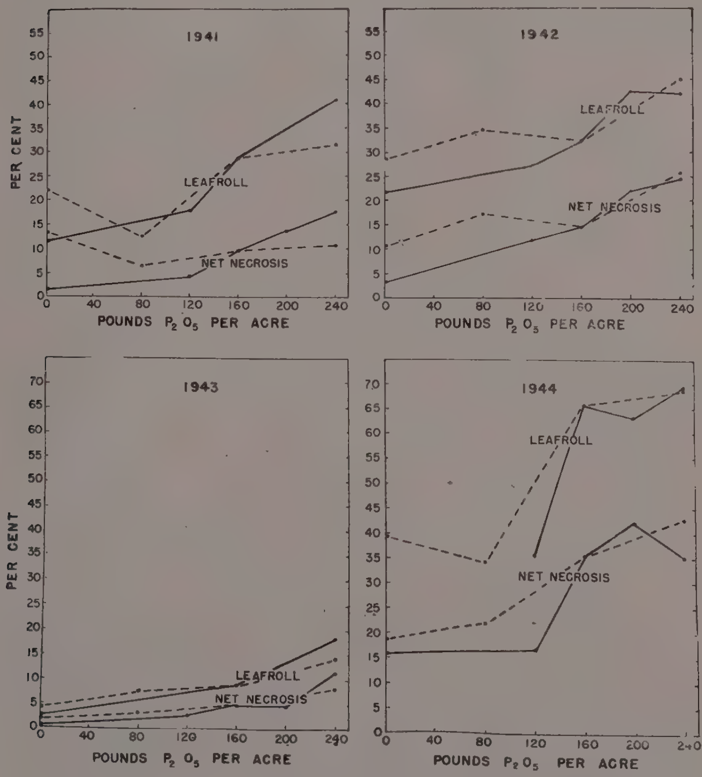

FIGURE 3. The relationship between rate of phosphorus application and the amount of net necrosis and leafroll in the crop from the permanent plots. The solid lines represent data obtained from plots receiving different amounts of a 4-8-8 mixture and the broken lines those from plots receiving 2000 pounds per acre of mixtures containing varying amounts of P_2O_5.

Phosphorus deficient plants tend to grow for a longer period of time than those receiving sufficient phosphorus. They remain green and succulent at the time that aphid populations become large and the greatest amount of leafroll spread occurs. It would appear that phosphorus or the phosphorus carrier plays a very peculiar role in relation to leafroll. On the one hand, it apparently increases the plant's susceptibility to leafroll virus by some unknown mechanism, and this increase is proportional to the amount of phosphorus supplied in the fertilizer. On the other hand, a deficiency of this element produces a condition that favors leafroll infection. The relative importance of these two opposing factors probably varies with unknown environmental or seasonal factors.

The data just discussed offer no evidence as to whether or not the effect noted is due to phosphorus itself or to some other ingredient of the phosphate carrier. As the superphosphate used in preparing the mixtures contained considerable gypsum the response could be due to calcium or to sulfur. However, it can be noted from the data in Table 4 that the addition of calcium limestone (where ammonium sulfate or ammonium chloride was used as source of nitrogen) had no consistent effect on the amount of net necrosis developed. The addition of sulfate (as ammonium sulfate) likewise had no consistent effect although there was some tendency toward an increase in net necrosis development where it was used. Data will be presented in a later section that give additional evidence that it is phosphorus itself that affects the amount of leafroll spread and the amount of net necrosis.

POTASSIUM—STEM-END BROWNING

Potassium Ratio—Permanent Plots. The proportion of potash carrier in the fertilizer had a very definite effect on the amount of stem-end browning in the stored crop (Table 8). In each of the four years, increasing the amount of potash carrier resulted in progressively greater percentages of stem-end browning in the stored crop. The only exceptions were that in a few cases the use of a 4-8-10 mixture failed to result in more stem-end browning than did the use of a 4-8-8 mixture. Without exception, the plots fertilized with a 4-8-12 fertilizer produced potatoes with a much higher incidence of disease than did those receiving mixtures containing lower proportions of K_2O.

In Figure 4 the data from Tables 1 and 8 are plotted as a function of the amount of K_2O applied. It is clear that the correlation between rate of fertilizer application and stem-end browning (Table 1) can be accounted for by the amount of potash carrier applied to the plots. It can also be noted that at high levels, a given amount of potash results in a higher percentage of stem-end browning when applied as a high K_2O fertilizer (4-8-12) than does the same amount of potash supplied in a 4-8-8 mixture. Although fertilizers with a high proportion of either nitrogen or of phosphorus did not have any important effect on the incidence of stem-end browning in the crop, there was a slight tendency in each case toward a decrease in the amount of stem-end browning. It may be that in the case of an excess of both of these fertilizer constituents, the depressing effect on stem-end browning development may have been enhanced.

TABLE 8

The Effect of the Proportion of Potash in Potato Fertilizer on Stem-end Browning

Permanent Plots

Rotation	Treatment[1]	Stem-end browning						Yield per acre				
		1941	1942	1943	1944		Av.					
					Sev.	Total		1941	1942	1943	1944	Av.
		%	%	%	%	%	%	Bu.	Bu.	Bu.	Bu.	Bu.
3-year	4-8-0	0.5	1.1	0.0	0.1	1.7	0.8	233	137	263	183	204
	4-8-4	3.6	11.8	3.7	0.1	8.1	6.8	432	328	412	358	383
	4-8-8	21.4	36.8	36.7	3.9	26.3	30.3	473	361	417	380	4[illegible]9
	4-8-8[2]	15.1	35.0	26.5	5.2	23.2	25.7	456	375	434	385	4[illegible]3
	4-8-10	20.9	34.7	48.2	9.2	30.6	33.6	476	398	465	416	4[illegible]9
	4-8-12	48.2	44.2	58.6	13.4	36.3	43.8	500	407	435	428	443
Continuous cropping	4-8-8	21.4	52.7	39.6	27.0	49.0	40.7	442	387	511	361	425
	4-8-10	25.3	50.0	26.2	25.4	35.6	34.3	459	383	518	385	437

[1] 2000 pounds per acre.
[2] See footnote 2, Table 4.

Potassium Ratio—Other Fields. On commercial fields the results were not always consistent (Table 9). On some fields there was a definite tendency for high potash applications to result in high stem-end browning counts but on others no such tendency was noted. On a field not previously fertilized (Table 12) a 4-8-8 mixture resulted in considerably more stem-end browning than did a 4-8-0 application.

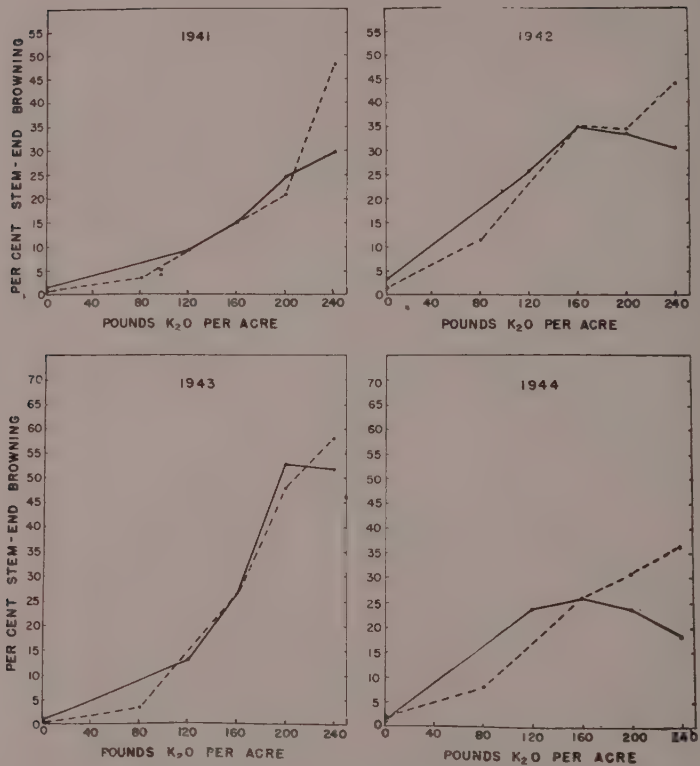

FIGURE 4 Stem-end browning in permanent plot samples as related to the amount of potash applied in the fertilizer. The solid line represents data from plots where varying amounts of a 4-8-8 mixture were applied. The broken line represents data from plots receiving 2000 pounds per acre of mixtures varying in potash content.

It is apparent that the results on the permanent plots are largely due to the cumulative effect of each fertilizer application over a period of years. The effect of the fertilizer ratio used during the current season appears to be of only minor importance.

Source of Potash—Permanent Plots. The fact that the incidence of stem-end browning in the crop is correlated with the amount of potassium in the fertilizer does not necessarily mean

TABLE 9

The Effect of the Proportion of Potash in the Potato Fertilizer on Stem-end Browning

Commercial Fields

Year	Source of potash	Treatment[1]	Stem-end browning[2] Farm 1	Stem-end browning[2] Farm 2	Stem-end browning[2] Farm 3 Sev.	Stem-end browning[2] Farm 3 Total	Net necrosis[2] Farm 1	Net necrosis[2] Farm 2	Net necrosis[2] Farm 3
			%	%	%	%	%	%	%
1941	KCl	4-8-8	42.0	11.1			1.9	18.1	
		4-8-10	38.5	6.9			1.1	20.5	
		4-8-12	33.2	6.9			0.7	19.1	
		4-8-16	31.8	7.2			2.2	26.2	
		Average	36.4	8.0			1.5	21.0	
	K_2SO_4	4-8-8	19.3	5.3			3.1	14.8	
		4-8-10	30.5	5.1			1.0	16.5	
		4-8-12	28.9	6.9			1.5	8.2	
		4-8-16	14.4	4.8			0.5	12.1	
		Average	23.3	5.5			1.5	12.9	
	⅓ KCl ⅓ K_2SO_4 ⅓ KNO_3	4-8-8	6.4	7.1			2.8	12.2	
		4-8-10	11.7	3.6			1.3	19.0	
		4-8-12	26.5	6.3			0.0	18.6	
		4-8-16	43.9	11.3			0.9	19.1	
		Average	22.1	7.1			1.3	17.2	
1944	—	6-9-0			0.0	0.0			62.1
	KCl	2-6-5			3.7	6.5			40.7
		2-6-8			6.7	17.5			38.3
		2-6-11			2.7	7.1			51.8
		2-6-14			13.5	18.0			47.7
		8-6-5			3.2	9.1			56.4
		8-6-8			5.6	6.7			72.2
		8-6-11			3.5	11.5			56.2
		8-6-14			5.6	14.0			50.5

[1] 2000 pounds per acre.
[2] Each figure for Farms 1 and 2 is the average of 6 one-bushel samples, each taken from single row plots (randomized blocks). Each figure for Farm 3 is based on one or two one-bushel samples (Factorial Design).

that potassium itself is the active ingredient. In fact, data obtained on other plots show conclusively that the type of carrier used markedly affects the amount of stem-end browning (Table 10). In each of the four years, the tubers from the plot receiving potassium in the form of the muriate were higher in stem-end browning than those produced on plots where potassium sulfate was used. Over a period of years both sources of potash were equally effective as far as yield is concerned and the potatoes from plots fertilized with K_2SO_4 were higher in total solids and in starch (4). It may also be noted that the KCl plots that were limed produced tubers that developed more stem-end browning than did

those from the corresponding unlimed ones. On the other hand, where K_2SO_4 was used as source of potash, liming had no consistent effect on the amount of stem-end browning in the stored crop. These plots were limed to the point where scab appeared. It does not seem probable that smaller amounts of lime would affect the amount of stem-end browning appreciably.

TABLE 10

The Effect of Source of Potash in the Potato Fertilizer on Stem-end Browning in the Stored Crop

Permanent Plots—3-year Rotation

Treatment[1]	Source of potash	Stem-end browning						Yield per acre				
		1941	1942	1943	1944		Av.	1941	1942	1943	1944	Av.
					Sev.	Total						
		%	%	%	%	%	%	Bu.	Bu.	Bu.	Bu.	Bu.
4-8-8	KCl	12.0	33.6	10.1	6.5	26.0	20.4	456	396	448	372	418
4-8-8	K_2SO_4	4.7	27.5	6.4	4.1	15.5	13.5	436	372	439	387	409
4-8-8 (Limed)[2]	KCl	23.6	33.0	23.4	10.4	35.3	28.8	422	388	428	382	405
4-8-8 (Limed)[2]	K_2SO_4	4.8	24.4	8.5	2.9	24.5	15.6	403	373	445	391	403

[1] 2000 pounds per acre. The KCl and K_2SO_4 plots were adjacent. One-half of each was limed.

[2] Calcium limestone applied at the average rate of 2000 pounds per acre following potato harvest from 1927 up to and including 1935.

Source of Potash—Other Fields. The effect of different sources of potash when applied to commercial potato fields was also determined (Tables 9 and 11). The results are quite erratic; during some years or on some fields, the source of potash made no difference, while on others the use of sulfate resulted in less stem-end browning.

In 1944 a test was conducted on a field not previously fertilized (Table 12). Even here those tubers from the KCl plots contained on the average no more stem-end browning than did those from the K_2SO_4 plots and only slightly more than those from plots supplied with KNO_3. The addition of NaCl to a mixture relatively free of chloride did not increase the incidence of stem-end browning except where KNO_3 was used as source of potash although it did result in more severe discoloration. It is apparent from these data that the effect of chloride applications to the soil on the stem-end browning in the crop is most noticeable where it is used over a period of years.

TABLE 11

The Effect of Source of Potash on Stem-end Browning

Commercial Fields

Source of potash	Stem-end browning in stored crop[4]															
	1941[1]		1942[2]		1943[3]		1944[2]									
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5		Farm 6		Farm 7		Farm 8		Farm 9		Farm 10	
					Sev.	Total	Sev.	Total	Sev.	Total	Sev.	Total	Sev.	Total	Sev.	Total
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
KCl	39	7	24	66	7	17	12	16	10	36	4	12	8	10	4	32
K_2SO_4	31	5	25	65	7	22	4	9	14	34	2	8	5	10	1	15
½ KCl, ½ K_2SO_4	14	8	25	65	1	9										
¼ KCl, ¾ K_2SO_4	.				6	20										
⅓ KCl, ⅓ K_2SO_4, ⅓ KNO_3	12	4														
½ KCl, ½ KNO_3	42	10														
½ K_2SO_4 + ½ KNO_3	27	8														
KNO_3 + K metaphosphate			23	62	6	17										

[1] 2000 pounds per acre of 4-8-10.
[2] 2000 pounds per acre of 5-7-10.
[3] 2000 pounds per acre of 5-8-12.
[4] Average of 5 to 6 one-bushel samples. Either randomized blocks or Latin Square design.

TABLE 12

The Effect of Various Treatments on Stem-end Browning and Net Necrosis on a Field not Previously Fertilized

Fertilizer	Amount per acre	Source of potash	Yield per acre[1]	Stem-end browning[1]		Net necrosis[1]
				Sev.	Total	
			Bu.	%	%	%
None	—	—	88	3.5	12.8	36.7
4-8-0	2500	—	255	2.5	8.3	36.4
4-8-8	2500	KNO_3[2]	286	2.6	11.4	37.2
4-8-8	2500	K_2SO_4	315	4.3	16.9	37.2
4-8-8	2500	KCl	282	9.4	17.4	43.0
4-8-8	3500	K_2SO_4	338	4.2	17.3	43.2
4-8-8	3500	KCl	291	5.0	11.2	39.0
4-8-8 + NaCl	2500 + 500	KNO_3	285	10.4	22.4	44.0
4-8-8 + NaCl	2500 + 317[3]	K_2SO_4	301	6.9	14.5	47.7
4-8-8 + NaCl	3500 + 443[4]	K_2SO_4	282	6.7	14.8	36.4

[1] Average of 5 single row plots, each 24 feet long. Randomized block design.
[2] Fertilizer mixture prepared from technical grade ammonium phosphate, potassium nitrate and urea.
[3] Sufficient NaCl to give an amount of chloride equivalent to that in 2500 pounds of 4-8-8 fertilizer with KCl as potash carrier.
[4] Sufficient NaCl to give an amount of chloride equivalent to that in 3500 pounds of 4-8-8 fertilizer with KCl as potash carrier.

The data in Table 12 give some indication that potassium itself has an effect on the occurrence of stem-end browning. Similarly, in Table 9, increasingly large amounts of potash (as K_2SO_4) resulted in progressively greater amounts of stem-end browning in the stored tubers.

Changing the Source of Potash. The data in the preceding section indicate that a change from muriate of potash to other potassium salts does not always result in a reduction in the amount of stem-end browning in tubers produced the year the change is made. The question arose as to the possibility of continued use of K_2SO_4 on a field previously fertilized with the muriate. In order to study this the plots in the continuous cropping strip of the permanent plots were subdivided in 1942, with ½ of each plot receiving potassium in the form of the sulfate and the other in the form of the muriate. These treatments were continued in subsequent years. In 1944 the plots were further subdivided.

TABLE 13

The Effect of a Change in Source of Potash on Stem-end Browning
Permanent Plots—Continuous Cropping

Treatment	Source of potash	Stem end browning[4]							
		1941	1942	1943	1944 Keswick strain[1]		1944 Highmoor strain[2]		3-year average[3]
					Sev.	Total	Sev.	Total	
		%	%	%	%	%	%	%	%
2000 lbs. 4-8-8	KCl	21.4	52 7	39.6	27.0	49.1	7.1	15.6	47.1
	K_2SO_4		43.7	42.5	5.0	28.9	—	—	39.4
2000 lbs. 4-8-8 + peat	KCl	8 5	34.3	22.8	21.0	38.9	4.3	9.5	32.0
	K_2SO_4		39.0	37.9	9.8	26.8	2.8	6.0	34.6
2000 lbs. 4-8-8 + manure	KCl	23.1	48.0	48.0	11.6	19.6	5.3	14.9	38.5
	K_2SO_4		44.8	25.2	13.2	30.2	7.8	11.0	33.4
2500 lbs. 4-8-8	KCl	20.6	44.6	58.2	11.1	16.0	4.2	7.1	39.6
	K_2SO_4		50.0	40.3	9.8	27.3	5.8	11.6	39.2
2000 lbs. 4-8-10	KCl	25.3	50.0	26.2	25.4	35.6	3.8	10.2	37.3
	K_2SO_4		47.5	20.9	6.1	15.7	1.2	3.7	28.0
Average	KCl	19.8	45.9	39.0	19.2	31.9	—	—	38.9
Average	K_2SO_4		45.6	33.4	8.8	25.8	—	—	34.9

[1] Quite subject to stem-end browning development.
[2] Usually less subject to stem-end browning than the Keswick strain.
[3] The 1941 data and that on the Highmoor strain (1944) are not included in these averages.

One row of each half plot was planted with the same strain as used in previous years, namely, the Keswick strain. The other two rows were planted with the Highmoor strain which normally showed much less stem-end browning than the Keswick. In 1942, the first year the source of potash was changed, the plots receiving K_2SO_4 produced a crop that, on the average, contained as much stem-end browning as did that from plots receiving KC1 (Table 13). This is in accord with the results on commercial fields. In 1943 the crop from the plots which received K_2SO_4 as source of potash developed somewhat less stem-end browning on the average than did that from the plots receiving KC1. In 1944 the difference was still greater and was apparent in both strains. Although all plots did not behave in a like manner the averages show a definite trend and indicate that continued use of potassium sulfate as the source of potash would eventually result in decreased percentages of stem-end browning in the crops produced. The data in Table 10 can be interpreted as a measure of the effect of a change in source of potash in a 3-year rotation. In all probability the field where the permanent plots are located was originally fertilized with KC1-containing fertilizers and it is quite evident that continued use of K_2SO_4 on these plots reduced the amount of stem-end browning.

POTASSIUM—NET NECROSIS AND SPREAD OF LEAFROLL

Permanent Plots. The results in Table 14 show that the amount of potash in the fertilizer has some effect on net necrosis and the spread of leafroll. In general, increasingly larger proportions of potash in the fertilizer up to a 4-8-10 ratio results in small increases in the amount of net necrosis and to a lesser extent in the spread of leafroll. There is no consistent effect on the net necrosis/leafroll ratio except that the ratio in the tubers from the 4-8-0 plots was uniformly low. The results on the 4-8-0 plots should be in part discounted because of the fact that the plants die early and hence are not subject to the great increase in aphid population late in the season. The plants on plots receiving other treatments do not visibly differ in this respect.

In spite of the fact that the correlation between rate of potash application and disease incidence was small the source of potash

TABLE 14

Effect of Potash Ratio and Source of Potash on Net Necrosis and in Spread of Leafroll

Permanent Plots—3-year Rotation

Treatment[1]	Net necrosis					Leafroll				(Net necrosis/leafroll) X 100			
	1941	1942	1943	1944	Av.	1941	1912	1943	1944	1911	1942	1943	1944
	%	%	%	%	%	%	%	%	%	%	%	%	%
4-8 0	0.8	3.5	0.3	19.4	6.0	5.9	19.0	3.2	—	13.6	18.4	9.4	
4-8 4	6.2	15.0	6.2	25.3	13.2	2'.8	32.1	11.8	—	28.4	46.7	52.5	
4-8-8[2]	9.7	14.7	5.0	35.3	16.2	28.8	32.3	9.1	—	33.7	45.5	54.9	
4-8-10	8.0	18.2	8.7	36.2	17.8	17.1	'8.8	—	—	46.8	43.9	—	
4-8-12	11.6	14.7	3.4	34.7	16.1	33.4	36.3	7.1	—	34.7	40.5	47.9	
4-8-8[2] (KCl)[3]	8.0	14.4	9.3	25.3	14.3	12.9	24.1	12.5	44.2	62.0	59.8	74.4	57.2
4-8 8 (K_2SO_4)[3]	2.6	7.1	1.7	18.2	7.4	10.7	27.8	4.9	35.5	24.3	25.5	34.7	51.3
4-8-8 (KCl[3] + lime[4])	8.1	15.3	6.8	22.6	13.2	—	—	11.0	36.0			61.8	62.8
4-8 8 (K_2SO_4[3] + lime[4])	4.6	6.7	4.6	21.8	9.4	—	—	6.7	33.1			68.7	65.9
Average for KCl	8.1	14.9	8.1	24.0	13.8								
Average for K_2SO_4	3.6	6.9	3.2	20.0	8.4								

[1] 2000 pounds per acre (KCl as source of potash except where indicated).
[2] These two are duplicates.
[3] Source of potash.
[4] See footnote 2 in Table 10.

does have an important effect. In each of the four years, greater amounts of the disease were found in the crop from the plots where potash was supplied as the muriate than in that from plots where the sulfate was used. This was true for both the limed and unlimed halves.

Other Fields. Data on the amount of net necrosis in tubers produced on plots receiving various amounts and sources of potash are contained in Tables 9 and 15. In 1941 (Table 9), the potash ratio had no effect on the amount of net necrosis but, on the average tubers from the KC1 plots developed the most net necrosis. In 1944 the proportion of potash in the fertilizer likewise had no effect on net necrosis. In all, sources of potash comparisons were made on 11 farms and on 7 of them the tubers from the plots receiving KC1 developed the most net necrosis.

On the field that had not previously been fertilized (Table 12) there was very little difference in net necrosis content in the crop from the various treatments. It is interesting to note that on land not previously fertilized, a fairly high percentage of net necrosis was obtained even on the plot fertilized with salts containing no appreciable amounts of nutrient elements other than N, P, and K.

Change of Source of Potash. In 1942, the plots on the con-

TABLE 15

The Effect of Source of Potash on Stem-end Browning in the Stored Crop

Source of potash	Net necrosis in stored crop[4]									
	1941[1]		1942[2]		1943[3]	1944[2]				
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10
	%	%	%	%	%	%	%	%	%	%
KCl	1	21	20	14	4	45	31	19	35	33
K_2SO_4	1	17	10	8	1	35	37	18	32	18
½ KCl, ½ K_2SO_4	1	19	10	12	5					
⅓ KCl, ⅓ K_2SO_4, ⅓ KNO_3	1	19								
¼ KCl, ¾ K_2SO_4					1					
½ K_2SO_4, ½ KNO_3	2	5								
KNO_3 + K metaphosphate			9	5	1					
½ KCl, ½ KNO_3	1	15								

[1] 2000 pounds per acre of 4-8-10.
[2] 2000 pounds per acre of 5-7-10.
[3] 2000 pounds per acre of 5-8-12.
[4] Average of 5 or 6 one-bushel samples. Either randomized blocks or Latin Square design.

tinuous cropping strip were subdivided. One half of each continued to receive KCl as potash source while the other half received K_2SO_4. In each of the three years, the change to sulfate resulted

TABLE 16

The Effect of a Change in Source of Potash on Net Necrosis

Permanent Plots—Continuous Cropping

Treatment	Source of potash	Net necrosis					
		1941[1]	1942[2]	1943[2]	1944[2]	Average	
		%	%	%	%	3-yr. %	4-yr. %
2000 lbs. 4-8-8	KCl	4.1	20.6	5.2	17.6[3]	14.5	11.9
	K_2SO_4		22.4	8.7	23.9	18.3	
2000 lbs. 4-8-8 + peat	KCl	3.9	21.7	7.2	26.6	18.5	14.9
	K_2SO_4		16.0	0.8	16.3	11.0	
2000 lbs. 4-8-8 + manure	KCl	27.6	23.0	11.6	35.7	23.4	24.5
	K_2SO_4		17.0	8.6	28.4	18.0	
2500 lbs. 4-8-8	KCl	7.9	24.6	7.0	43.3	25.0	20.7
	K_2SO_4		20.3	3.2	30.3	17.9	
2000 lbs. 4-8-10	KCl	4.1	27.6	0.8	32.4	20.3	16.2
	K_2SO_4		13.5	2.7	32.7	16.3	
Average	KCl		23.5	6.4	31.1	20.3	
	K_2SO_4		17.8	4.8	26.3	16.3	

[1] Average of 6 one-bushel samples.
[2] Average of 3 one-bushel samples.
[3] 2 samples missing.

in a decrease in net necrosis in all cases, except where 2000 pounds of 4-8-8 (Table 16) or 4-8-10 were applied. The relative differences due to treatment were greater in 1943 than in 1942, but in 1944 they were smaller than in either of the previous two years. As 1944 was an abnormal year in that leafroll spread was very prevalent, other factors may have been of minor importance.

CHEMICALLY PURE SALTS

Seven plots on the 3-year rotation were fertilized since 1936 with a mixture prepared from chemically pure potassium nitrate, ammonium phosphate, and urea. Hence, the mixture differed from ordinary commercial fertilizer mixtures in that no elements other than N, P, and K (and of course C, H, and O) were present except possibly in trace amounts. Although minor elements are essentially absent from this mixture, no discernible symptoms of deficiencies have been noted on the plots so fertilized. However, these plots have usually failed to yield as well as other plots fertilized with ordinary fertilizers containing the same amounts of N, P_2O_5, and K_2O. Prior to 1936 these plots were a part of a 3-year rotation. Five of them were fertilized with high-analysis fertilizers and the remaining two were selected from plots used in a source of nitrogen study.

Stem-end Browning. The data in Table 17 clearly show that less stem-end browning resulted from the use of chemically pure salts than from the ordinary mixtures containing KCl as source of potash. However, the figures are only slightly lower than those for the plots fertilized with ordinary grade fertilizer containing K_2SO_4. Since the usual commercial grade K_2SO_4 contains some chloride, it seems quite likely that the difference in results between those for the "C.P." plots and those for the "regular check" mixtures is due largely if not entirely to the chloride content of the latter. The discrepancy could possibly have been due in part to the fact that all except the C.P. plots received a 1000 pound per acre application of lime in 1940. It has been noted that extensive liming tends to increase stem-end browning. However, the 1000 pound application was considerably less than that applied to the regularly limed plots and the effect would be expected to be proportionally less. Furthermore, the stem-end browning figures for the K_2SO_4 lime plots (Table 10) were on the average

not much greater than those for the C.P. plots and liming had an effect only when fertilizers high in chloride were used. Consequently it does not seem possible to explain the low readings on the C.P. plots to differences in liming practice. While it is true that the potassium sulfate plots have been established longer than the C.P. plots, it is also true that those plots in Series D had been fertilized prior to 1936 with chloride-free mixtures. Hence, this series should be comparable to the K_2SO_4 plots in respect to the length of time chloride-free fertilizers had been used.

TABLE 17

Stem-end Browning and Yield on Plots Fertilized with Chemically Pure Salts[1]

Permanent Plots—3-year Rotation

Series	Source of potash prior to 1936	Treatment since 1936[2]	Stem-end browning						Yield per acre				
			1941	1942	1943	1944 Sev.	1944 Total	Av.	1941	1942	1943	1944	Av.
			%	%	%	%	%	%	Bu.	Bu.	Bu.	Bu.	Bu.
A	⅓ KCl, ⅔ Nitrophoska	C.P.[3]	1.8	21.6	14.0	1.3	11.4	12.2	481	351	392	357	395
B	KCl	C.P.[4]	2.7	17.2	6.0	1.0	9.7	8.9	471	281	423	354	382
C	KCl	C.P.[4]	3.4	21.3	4.3	3.0	17.7	11.7	483	348	438	392	415
D	KNO_3	C.P.[4]	2.5	19.7	11.7	3.2	10.6	11.1	495	259	413	386	388
E	KCl	C.P.[4]	1.1	18.8	7.6	3.2	9.1	9.2	411	297	410	324	361
G	KCl	C.P.[4,6]	3.6	17.6	9.7	3.1	11.7	10.7	461	338	434	362	399
H	KCl	C.P.[5]	2.6	18.2	5.6	3.1	6.1	8.7	447	369	468	376	415
Average for all C.P. plots			2.5	19.2	8.4	2.6	10.9	10.3	464	320	425	364	394
Regular 4-8-8 (K_2SO_4)			4.7	28.1	6.4	6.4	15.5	13.7	436	372	439	387	409
Regular 4-8-8 (KCl)			21.4	36.8	36.7	3.9	26.3	30.3	476	361	417	380	409
Average of several 4-8-8 (KCl) plots[7]			13.9	34.4	26.8	5.2	26.2	25.7	457	387	433	385	416

[1] All applications equivalent to 2000 pounds of 4-8-8 per acre.
[2] C.P. denotes that the mixture was prepared from chemically pure salts.
[3] Magnesium applied in 1943 (20 pounds MgO per acre as sea water magnesium oxide).
[4] Magnesium applied in 1943 and 1944 (20 lbs. MgO per acre as sea water magnesium oxide).
[5] Magnesium applied in 1944 (20 pounds MgO per acre as sea water magnesium oxide).
[6] Boron added prior to 1943 and 1944 crops (boric acid applied to clover the previous year at rate equivalent to 20 pounds borax per acre).
[7] See footnote 2, Table 4.

The fact that the treatment prior to 1936 had no effect on the behavior of the plots from 1941 to 1944 is of special interest. While stem-end browning readings were not taken prior to 1941 it can be assumed, from the data in the preceding tables, that at least some of the plots, e.g., Series G and K, would have been relatively high in stem-end browning. As this was a 3-year rota-

tion, the 1941, 1942, and 1943 applications were the third applications of C. P. salts while in 1944 the fourth application was made. The data indicate that not more than three applications (in 5 years) are required to overcome the residual effect of previous applications of fertilizers high in chloride. Previous data have shown that a change to K_2SO_4 as potash source for three successive years on the continuous cropping strip was not as effective as the above. This does not necessarily mean that the use of K_2SO_4 is less effective in reducing stem-end browning than C. P. salts for it should be recalled that K_2SO_4 test was made on the continuous cropping section where high chloride mixtures had been applied every year, a practice which might be expected to cause a greater build-up of the residual effect of chloride.

Net Necrosis and Spread of Leafroll. There was also considerably less net necrosis in the tubers produced on the C.P. plots than in those produced on plots receiving the regular type fertilizer containing KCl (Table 18). The data on leafroll are not sufficiently consistent to give clear-cut evidence as to whether this

TABLE 18

Net Necrosis and Leafroll in Tubers from Plots Fertilized with Chemically Pure Salts[1]

Permanent Plots—3-year Rotation

Series	Source of potash prior to 1936	Treatment since 1936[2]	Net necrosis					Leafroll				(Net necrosis/ Leafroll) X 100			
			1941	1942	1943	1944	Av.	1941	1942	1943	1944	1941	1942	1943	1944
			%	%	%	%	%	%	%	%	%	%	%	%	%
A	1/3 KCl, 2/3 Nitrophoska	C.P.[3]	1.6	9.3	5.3	17.4	8.4	—	—	—	39.1				44.5
B	KCl	C.P.[4]	4.1	3.8	2.4	18.8	7.3	8.3	22.8	—	43.6	49.4	16.7		42.9
C	KCl	C.P.[4]	3.5	5.5	2.6	20.6	8.1	10.0	20.5	—		35.0	25.8		
D	KNO3	C.P.[4]	3.7	6.4	3.0	31.9	11.3	16.4	—	10.0	65.1	22.6		30.0	49.0
E	KCl	C.P.[4]	2.3	4.1	1.9	20.6	7.2	13.3	—		49.3	17.3			41.8
G	KCl	C.P.[4,6]	2.8	5.1	3.7	19.5	7.8	—	—	6.8	—	—		54.4	
H	KCl	C.P.[5]	5.2	4.2	4.3	20.1	8.5	16.7	20.7	6.4	—	31.1	30.0	67.2	
Average for all C.P. plots			3.3	5.5	3.3	21.3	8.4	12.5	21.3	7.7	49.3	31.1	24.5	50.5	44.6
Regular 4-8-8 (K_2SO_4)			2.6	7.1	1.7	18.2	7.1	10.7	27.8	4.9	35.5	24.2	25.5	34.7	47.9
Regular 4-8-8 (KCl) 1/2 plot[7]			8.0	14.4	9.3	25.3	14.2	12.9	24.1	12.5	44.2	62.0	59.8	74.4	57.2
Regular 4-8-8 (KCl)[7]			9.7	14.7	5.0	35.3	16.2	28.8	32.3	9.1	65.4	33.6	45.5	54.9	54.0

[1] All treatments equivalent to 2000 pounds of 4-8-8 per acre.
[2] C.P. denotes that the mixture was prepared from chemically pure salts.
[3] Magnesium applied in 1943 (20 pounds per acre MgO as sea water magnesium oxide).
[4] Magnesium applied in 1944 (20 pounds per acre MgO as sea water magnesium oxide).
[5] Magnesium applied in 1943 and 1944 (20 pounds per acre MgO as sea water magnesium oxide).
[6] Boron added prior to 1943 and 1944 crops (boric acid applied to clover the previous year at a rate equivalent to 20 pounds borax per acre).
[7] These two are duplicates except for size and location.

reduction is due to an effect on the susceptibility to leafroll infection or on the net necrosis/leafroll ratio. In general it appears that it affects both. It is probably significant that the data from the C.P. plots are quite similar to those for the K_2SO_4 plots. Apparently the other extraneous materials in the K_2SO_4 containing fertilizer have little or no effect on net necrosis or on the spread of leafroll. Hence, it is improbable that the gypsum (or other extraneous ingredients) in superphosphate could have caused the increased incidence of disease caused by large applications of phosphate. It is much more probable that the results were due to phosphorus itself.

As in the case of stem-end browning, the treatments used prior to 1936 had no effect on the amount of disease obtained after changing to C.P. salts. Also, the period from 1936 to 1941 with three applications of C.P. salts was sufficient to overcome the residual effect of previously applied chloride.

ORGANIC MATTER

It is a common belief among potato growers that high organic matter applications lead to a high percentage of stem-end browning in the crop. The data in Table 19 provide some basis for this

TABLE 19

The Effect of Organic Matter on Stem-end Browning and Net Necrosis

Permanent Plot—2-year Rotation

Treatment[1]	Stem-end browning						Net necrosis				
	1941	1942	1943	1944		Av.	1941	1942	1943	1944	Av.
				Sev.	Total						
	%	%	%	%	%	%	%	%	%	%	%
A. Crimson clover cut and removed	13.7	34.5	12.4	2.8	18.4	19.6	9.3	14.0	6.2	36.2	16.4
B. Crimson clover plowed under	19.0	35.2	29.7	14.4	35.6	29.8	19.2	17.3	3.1	38.7	19.8
C. Crimson clover from plots A and C plowed under	15.3	40.8	23.5	13.7	39.7	29.8	17.7	16.5	9.8	36.1	19.9
D. Crimson clover plus 6 tons[2] straw plowed under	19.4	39.0	42.6	17.0	39.5	35.1	11.4	20.7	2.8	34.0	17.3
E. Crimson clover plus 20 tons[2] manure plowed under	21.3	25.3	37.7	18.3	42.7	32.7	14.8	30.2	14.3	31.7	22.7

[1] All plots received 2000 pounds of 4-8-8 per acre.
[2] Rate per acre.

belief but the effect is not great. Removal of the crimson clover crop did tend to decrease both the amount of stem-end browning and net necrosis in the subsequent potato crop. Doubling the amount of crimson plowed under had no further effect. Plowing under straw (6 tons per acre) or manure in addition to the normal crop of crimson clover tended to cause slight increases in the amount of stem-end browning. The latter treatment also gave a slight increase in the amount of net necrosis. It should be noted, however, that the plots receiving very high amounts of organic matter were a little higher on the average than the 4-8-8 plots on the 3-year rotation where clover was plowed under only once every three years. In the case of the continuous cropping strip, applications of organic matter had no effect on the amount of stem-end browning (Table 13), but did result in increase in the amount of net necrosis (Table 16).

ACID VERSUS NEUTRAL MIXTURES

There was practically no difference between the amount of stem-end browning or net necrosis in the potatoes produced on the plot fertilized with an acid mixture and in those from plots receiving neutral mixtures (Table 20). These plots were established in 1936.

TABLE 20

Stem-end Browning on Plots Fertilized with Acid Mixtures in Comparison with Those Receiving Neutral Mixtures

Permanent Plots—3-year Rotation

Treatment[1]	Stem-end browning				Net necrosis			
	1941	1942	1943	Av.	1941	1942	1943	Av.
	%	%	%	%	%	%	%	%
Acid mixture[2]	12.3	29.5	25.2	22.3	7.1	18.4	2.7	9.4
Acid mixture + Kieserite	10.3	35.3	31.8	25.8	11.0	17.7	5.3	11.3
Acid mixture + dolomitic limestone[3]	15.1	35.9	28.8	26.6	8.9	20.9	5.1	11.6
Acid mixture + calcium limestone[3]	11.4	32.8	22.5	22.2	8.2	15.7	3.1	9.0
Average of neutral mixtures	12.3	34.7	27.7	24.9	9.4	18.1	4.5	10.6

[1] All treatments equivalent to 2000 pounds per acre of 4-8-8.
[2] Seven-tenths of the nitrogen from ammonium sulfate and three-tenths from fish meal.
[3] In amounts sufficient to neutralize the equivalent acidity of the acid mixture.

ROTATION

Several identical treatments appeared on each of the three types of rotations. Hence it is possible to determine the effect of type of rotation on the prevalence of stem-end browning and net necrosis in the crop. In view of the wide differences in practice used in the three types of rotations it is surprising that the potatoes in each did not differ appreciably in stem-end browning or net necrosis content (Table 21). There was a slight correlation between stem-end browning and frequency of cropping to potatoes but this was so slight that for all practical purposes it may be said that the potatoes produced in the three types of rotations did not differ in disease content.

TABLE 21

Stem-end Browning and Net Necrosis as Affected by Type of Rotation

Permanent Plots

Treatment	Rotation	Stem-end browning					Net necrosis				
		1941	1942	1943	1944	Av.	1941	1942	1943	1944	Av.
	year	%	%	%	%	%	%	%	%	%	%
2000 lbs. 4-8-8	1	21.4	52.7	39.6	49.0	40.7	4.1	20.6	5.2	17.6	11.9
	2	19 0	35.0	29.7	35.6	29.8	19.2	18.0	3.1	38.7	19.8
	3	21.4	36.8	36.7	26.3	30.3	9.7	14.7	5.0	35.3	16.2
	3[1]	15.1	35.0	25.5	26.2	25.7	9.5	13.6	5.1	30.3	14.6
2000 lbs. 4-8-10	1	25.3	50.0	26.2	35.6	34.3	4.1	27.6	0.8	32.4	16.2
	3	20.9	34.7	48 2	30.6	33.6	8.0	18.2	8.7	36.2	17.8
2500 lbs. 4-8-8	1	20.6	44.6	58.2	16.0	34.9	7.9	24.6	7.0	43.3	20.7
	3	24.8	33.7	52.8	23.8	33.8	13.6	22.0	4.9	42.0	20.6
2000 lbs. 4-8-8 plus 20 tons manure per acre	1	23.1	48.0	48.0	19.6	34.7	27.6	23.0	11.6	35.7	24.5
	2	24.3	26.0	37.7	42.7	32.7	14.8	30.0	14.3	31.7	22.7
4-8-8 (Nitrate of soda)[2]	2	15.6	42 0	30.8	—	29.5	12.2	11.0	2.9		8.7
	3	15.7	38.0	24.4	—	26.0	6.8	16.5	4.4		9.2
4-8-8 (Sulfate of ammonia)[2]	2	7.3	32 0	18.4	—	19.2	13.3	16.0	10.7		13.3
	3	14.6	36.6	27.9	—	26.4	12.0	9.2	4.6		8.6

[1] Average of several 4-8-8 plots. See footnote 2 in Table 4.
[2] Source of nitrogen.

SEASONAL FACTORS

The crop produced on a given type of plot did not develop the same amount of stem-end browning each year. Furthermore, the seasonal variation for one type of plot did not necessarily

coincide with that for another type. There is apparently some relationship between low seasonal yields and high stem-end browning for a given type of plot. If the 1943 data are ignored, the correlation is good except for the high potash plots (2000 pounds of 4-8-12 or 3000 pounds of 4-8-8) and some of the high organic matter plots. That is, for plots receiving low to medium high applications of fertilizer, seasons of high yield were characterized by low percentages of stem-end browning and seasons of low yields by high percentages. The records indicate that the low yields in the years studied were probably due to drought conditions during July or August. The suggestion that high rainfall during the growing season results in a low incidence of stem-end browning is not surprising. In such seasons, the relative concentration of the nutrient elements in the soil solution might be expected to be less than in dry seasons. That is, in a season of high rainfall, a 2000 pound application of fertilizer could conceivably produce conditions somewhat similar to those created by a 1500 pound application or less in a dry season. If large excesses of nutrients are supplied, these seasonal differences would be negligible.

The 1943 data do not fit in with the preceding hypothesis. On most plots, the percentages of stem-end browning were much higher than would be expected if the supposition were true. On low-chloride plots this discrepancy did not exist. It has been shown that in Aroostook County late planting is conducive to high stem-end browning (14). Except for 1943, the permanent plots were planted the week of June 1. In 1943, they were planted on June 9 and 10. It is possible that this fact accounts for the disagreement of the 1943 data with those of other years.

As the biggest factor affecting the spread of leafroll and amount of net necrosis is aphid population, this report contains insufficient data to evaluate other seasonal factors. Comparisons can be made of seasonal variations in the net necrosis/leafroll ratio. For most treatments, this ratio tended to increase with each successive year, especially from 1941 through 1943. This trend does not appear to be correlated with any recorded climatological data, date of planting, date of harvest, or prevalence of leafroll.

MINOR ELEMENTS

Most of the following experiments were conducted on Caribou loam, the predominant soil type in the potato growing area of Aroostook County, Maine. The Green Mountain variety was used exclusively. In most cases the minor elements were added to ordinary commercial fertilizer but in some cases special mixtures were prepared. Unless otherwise stated the mixtures were band placed by machine. In still other cases, the minor elements were applied as a spray. Some of the elements were applied at different rates, but this was not possible in all cases. In general, a given salt was applied at a rate calculated to be just short of the toxic range. Since in some cases there was very little or no information in the literature upon which to base such calculations, the aim was not always realized.

Boron. It has been found that some soils in Maine contain insufficient amounts of boron to produce normal crops of certain species in the genus *Brassica* (2). Boron deficiency in field-grown potatoes has been reported from time to time in this country (12), and some preliminary results of greenhouse experiments with

TABLE 22

Effect of Borax Sprays on Yield, Net Necrosis and Stem-end Browning

Concentration	Number of applications[1]	Borax applied per acre	Yield[2] per acre	Stem-end browning[2]	Net necrosis[2]
%		lb.	bu.	%	%
Control	—	0	384	18.5	4.8
0.1	4	5.5	383	19.9	5.2
0.5	3	19.3	361	20.0	4.0
1.0	1[4]	10.4	343	20.4	4.0
2.0	1[4]	20.9	350	23.2	5.0
Minimum difference required for significance			74		
Control	—	0	374	13.7	7.4
0.5	1	8.3	338	16.4	3.4
0.5	2	9.9	309	15.6	2.4
0.5	4[3]	25.5	322	11.1	8.5
0.5	5[3]	30.3	324	19.0	8.5
Minimum difference required for significance			51		

[1] First spray applied when plants were in bud. Subsequent sprays at approximately 1 week intervals 3 or 4 days after the regular application of Spray-Cop.
[2] Average of 5 replicates, each 29 feet long from a Latin Square.
[3] Moderate burning of leaves by the sprays.

potatoes grown in sand indicated that stem-end browning might possibly be a symptom of mild boron deficiency (3). Consequently, a fairly extensive study of the effect of boron on field-grown potatoes was made.

The results of an experiment in which boron, as borax, was applied as a spray are presented in Table 22. In some cases sufficient borax was applied to cause leaf burning and significant decreases in yield, and yet no effect on stem-end browning was apparent. The effect on the occurrence of net necrosis was slight and independent of the total amount of borax applied. Results on three other plots substantiated the above.

In still another experiment, borax was added directly to the regular potato sprays. The addition of borax to the spray had no consistent effect on the amounts of stem-end browning or on net necrosis that developed (Table 23).

TABLE 23

Effect of Borax When Added to Regular Potato Sprays on Stem-end Browning and Net Necrosis—1943

Regular spray[1]	Amount of borax added[1]	Yield[2]	Stem-end browning[3]	Net necrosis[3]
	lbs./100 gal.	Bu./A.	%	%
10-5-100 Bordeaux	0	543	13.0	8.9
	1	536	19.3	15.4
	3	542	14.3	7.0
	6	513	19.9	9.6
0-5-100 Basi-cop	0	5[illegible]2	29.9	6.0
	3	530	29.9	9.6
Minimum difference required for significance		43		

[1] Six applications each of about 75 gallons, were made during the growing season.
[2] Average of 8 single row plots, each 75 feet long.
[3] Average of three one-bushel samples, each composed of tubers taken at random from 5 single row plots.

Data were obtained also on the effect of adding boron carriers to regular potato fertilizer. The results reported in Table 24 were obtained in 1943 and indicated a definite tendency of borax applications to reduce the amount of stem-end browning in the crop. The reduction, however, was accompanied by a marked decrease in yield. In 1944, borax had no effect on the amount of either net necrosis or of stem-end browning on a field not previously fertilized but fertilized with a mixture low in chloride that year.

TABLE 24

Effect of Borax in Potato Fertilizer on Yield, Stem-end Browning and Net Necrosis

Year	Treatment (per acre)		Yield per acre	Stem-end browning	Net necrosis
	Fertilizer[1]	Supplement	Bu.	%	%
1943[2]	1334 lbs. 6-9-15	None	545	21.1	2.1
		5 lbs. borax	539	18.6	1.8
		15 lbs. borax	487	15.4	1.0
		25 lbs. borax	483	8.6	1.0
1944 (New land)	2500 lbs. 4-8-8	None	286	11.4	37.2
		10 lbs. borax	268	13.6	35.6
		500 lbs. sodium chloride	285	22.4	44.0
	(Tech. grade salts)	500 lbs. sodium chloride plus 10 lbs. borax	309	20.9	41.1

[1] Band placement by machine. Supplement was mixed with the fertilizer.
[2] The 1943 yields are based on 12 randomized single row plots, each 50 feet long. Minimum difference in yield required for significance was 22 bushels. The figures for net necrosis and stem-end browning are the averages of 3 one-bushel samples, each a composite sample taken from several rows.
[3] The 1944 data are the averages of 5 single row plots, each 24 feet long. Randomized block design.

It was thought possible that the toxic effect of boron may have operated early in the growing season and that late in the season, when rapid growth of tubers took place, the amount of boron present in the soil may not have been sufficient for the production of normal tubers. In 1944 other boron carriers, calculated to provide boron slowly over the entire season, were included along with further tests with borax. In these tests, special fertilizer mixtures, using different potash carriers, were prepared (Table 25). In the amounts applied the spent boron catalyst and both types of boron silicate glass were quite toxic (Figure 5). The appearance of the plants and the reductions in yield indicated that the availability of boron in the spent boron catalyst is about half that of borax while that of the borax silicate glass is approximately the same as in the case of borax. None of the treatments eliminated either stem-end browning or net necrosis and significant reductions were obtained only where the yield was markedly reduced.

In 1943 and 1944, boron equivalent to that in 20 pounds of borax per acre was applied to one of the "C.P." plots of the permanent plot series (Tables 17 and 18). In neither year did the treatment significantly affect the amount of net necrosis or stem-end browning. It should be noted that on these plots boric acid was

FIGURE 5. Boron Toxicity in field grown Green Mountain potatoes with mixtures containing Corning Borax Silicate Glass. The center row received no boron carrier, that to the left received 75 pounds per acre and that on the right 150 pounds. Picture by E. K. Walrath.

broadcast on clover the previous year and plowed under, thus avoiding the danger of toxicity due to localization of the boron in the fertilizer band.

The results on boron taken as a whole indicate no definite relationship between the amount of boron applied and the amount of either stem-end browning or net necrosis in the crop. In some cases amounts of boron sufficient to decrease the yield did reduce the amount of discoloration. This fact does not indicate that the development of either stem-end browning or net necrosis is related to a deficiency of boron. If the diseases were due to a deficiency it would not seem reasonable that toxic amounts would be required for prevention. The use of boron certainly does not offer a practical solution to the problem.

Other Elements. Several other elements were tested, both in sprays (Table 26) and when added to the fertilizer (Tables 27

TABLE 25

The Effect of Adding Borax and Spent Boron Catalyst to Potato Fertilizer

Field	Boron carrier[1] rate per acre	KCl as source of potash: Yield per acre	KCl: Stem-end browning Sev.	KCl: Stem-end browning Total	KCl: Net necrosis	K_2SO_4 as source of potash: Yield per acre	K_2SO_4: Stem-end browning Sev.	K_2SO_4: Stem-end browning Total	K_2SO_4: Net necrosis
		Bu.	%	%	%	Bu.	%	%	%
1[2]	None	356	5.4	31.4	30.9	367	1.9	15.5	26.8
	10 lbs. Borax	317	5.3	24.8	33.7	318	2.9	25.8	26.6
	25 lbs. Borax	279	5.1	28.2	26.4	275	6.4	19.8	35.4
	75 lbs. Spent Boron Catalyst[4]	293	5.4	28.6	27.3	298	5.0	21.1	25.9
	150 lbs. Spent Boron Catalyst[4]	271	3.1	17.1	28.9	243	2.7	17.5	19.6
2[3]	None					371	31.5	58.8	26.0
	75 lbs. Borax glass 702 AP[4]					175	5.5	40.3	25.4
	150 lbs. Borax glass 702 AP[4]					128	7.4	34.7	31.0
	75 lbs. Borax glass 702 AQ[4]					234	13.0	50.9	25.2
	150 lbs. Borax glass 702 AQ[4]					171	11.6	46.3	19.7

[1] Added to a 5-7-10 fertilizer, which was applied at the rate of 2000 pounds per acre.
[2] Average of 5 single row plots, each 29 feet long. Randomized block design. Difference in yield required for significance at 5% level is 39 bushels.
[3] Average of 5 single row plots, each 29 feet long. Latin Square design. Difference in yield required for significance at 5% level is 17 bushels.
[4] These products were supplied by the Corning Glass Co. The spent boron catalyst contained 7.6 per cent boron. The borax silicate glass contained 16.2 per cent boron in 702 AP and 10.8 per cent boron in 702 AQ.

TABLE 26

The Effect of Spraying Potatoes with Minor Elements on Yield, Net Necrosis, and Stem-end Browning

Year	Compound	Concentration	No. of applications[1]	Rate of application per acre	Yield per acre	Stem-end browning	Net necrosis
		%		lb.	Bu.	%	%
1943[2]	Control	—	—	—	336	45.0	20.7
	$ZnSO_4 \cdot 7H_2O$	1.0	3	7.4(Zinc)	322	52.8	14.2
	$MnSO_4 \cdot H_2O$	1.0	3	11.4(Manganese)	371	47.0	10.4
	KI[3]	0.2	3	4.6(Iodine)	284	45.4	5.0
	$Na_2MoO_4 \cdot 2H_2O$	0.2	3	2.1(Molybdum)	380	43.9	21.6
	$CdCl_2 \cdot 2\frac{1}{2}H_2O$	0.2	2	1.9(Cadmium)	300	45.3	11.9
	$SrCl_2 \cdot 6H_2O$	0.2	3	2.0(Strontium)	402	45.6	18.4
	$Cr_2(SO_4)_3 \cdot 15H_2O$	0.2	3	0.9(Chromium)	355	55.1	6.9
1944[4]	Control	—	—	—	356	11.1	31.5
	$Cr_2(SO_4)_3 \cdot 15H_2O$	0.2	3	1.2(Chromium)	376	16.6	31.1
	$Cr_2(SO_4)_3 \cdot 15H_2O$	0.2	5	2.0(Chromium)	340	9.2	40.4

[1] The first spray was applied when most plants were in bud and subsequent sprays at approximately weekly intervals. Application was made 3 to 4 days after the regular spray with Spray-Cop.
[2] Each figure for this field is the average of 6 single row plots, each 29 feet long. Randomized block design. Minimum difference in yield required for significance is 58 bushels.
[3] Some burning of leaves by the sprays.
[4] Each figure for this field is the average of 6 single row plots, each 29 feet long. Latin Square design.

TABLE 27

Effect of Some Minor Elements Added to Potato Fertilizer on Yield, Stem-end Browning, and Net Necrosis

Year	Treatment (rate per acre)		Yield per acre	Stem-end browning	Net necrosis
	Fertilizer	Supplement	Bu.	%	%
1941[1]	1000 lbs. 8-16-16	None	403	18.0	15.9
		10 lbs. Cupric chloride ($CuCl_2 \cdot 2H_2O$)	400	17.2	10.5
		50 lbs. Cupric chloride ($CuCl_2 \cdot 2H_2O$)	358	11.9	11.3
		100 lbs. Cupric chloride ($CuCl_2 \cdot 2H_2O$)	279	13.3	10.7
		50 lbs. Calcium fluoride (CaF_2)	423	18.2	14.0
		25 lbs. Zinc sulfate ($ZnSO_4 \cdot 7H_2O$)	407	10.6	23.1
1942[2]	1250 lbs. 8-16-20	None	402	47.6	10.8
		20 lbs. Barium chloride ($BaCl_2 \cdot 2H_2O$)	392	46.0	13.3
		20 lbs. Bismuth chloride ($BiCl_3$)	403	44.3	10.0
		20 lbs. Cadmium chloride ($CdCl_2 \cdot 2\frac{1}{2}H_2O$)	392	27.9	10.2
		20 lbs. Lithium chloride ($LiCl$)	430	45.2	10.2
		20 lbs. Strontium chloride ($SrCl_2 \cdot 6H_2O$)	451	45.3	6.9
1944[3]	1600 lbs. 6-9-15	None	356	11.1	31.5
		5 lbs. Chromic sulfate ($Cr_2SO_4 \cdot 15H_2O$)	352	14.1	31.6
		20 lbs. Chromic sulfate ($Cr_2SO_4 \cdot 15H_2O$)	344	12.9	36.3
		5 lbs. Potassium dichromate ($K_2Cr_2O_7$)	350	12.1	32.4
1944[4] (New land)	3500 lbs. 4-8-8	None	291	11.2	39.0
		50 lbs. Copper sulfate ($CuSO_4 \cdot 5H_2O$)	290	14.6	36.7

[1] Yield data based on 3 rows, each 95 feet long. Stem-end browning and net necrosis data based on 3 one-bushel samples, each taken from a single row.
[2] Each figure for this field is the average of 4 single row plots, each 24 feet long. Minimum difference in yield required for significance is 66 bushels.
[3] Each figure for this field is the average of 6 single row plots, each 29 feet long.
[4] This field was not previously fertilized. All figures are the averages of 5 single row plots, each 24 feet long.

and 28). Zinc, manganese, iodine, molybdenum, cadmium, strontium, chromium, fluorine, barium, bismuth, lithium, cobalt, vanadium, and bromine had no consistent effect on the occurrence of stem-end browning. In 1941, the copper salt tended to reduce the amount of stem-end browning but it also depressed the yield considerably. The application of copper sulfate to new land had no effect on yield, the amount of net necrosis, or the amount of stem-end browning. A few of those tested appeared to reduce the incidence of net necrosis some years but if all of the data are considered it appears that the reductions were either due to experimental error or related to the toxic effect of the concentrations used. Iodine and cadmium applied as sprays caused leaf burning and the former caused a significant decrease in yield. Cadmium added to the fertilizer, in amounts greater than were applied as a spray, did not affect the amount of net necrosis. Chromium applied in sprays

TABLE 28

The Effect of Some Minor Elements Added to Potato Fertilizer on Stem-end Browning and Net Necrosis

1944

Field	Treatment[1]		Yield per acre	Stem end browning	Net necrosis
	Compound added	Rate of application per acre			
			Bu.	%	%
1[2]	None		380	56.6	26.9
	Cobalt chloride	5 lbs. Cobalt	266	55.4	25.1
	Sodium vanadate	2 lbs. Vanadium	317	47.6	37.8
2[3]	None		413	20.1	42.2
	Strontium chloride	1 lb. Strontium	394	20.7	43.4
	Strontium chloride	2 lbs. Strontium	395	20.4	49 2
	Strontium chloride	5 lbs. Strontium	403	20.7	41.0
	Strontium chloride	10 lbs. Strontium	424	20.3	43.5
3[2]	None		350	33.2	37.7
	Sodium bromide	0.5 lb. Bromine	351	24.3	30.0
	Sodium bromide	1.0 lb. Bromine	365	26.8	40.1
	Sodium bromide	5.0 lbs. Bromine	307	27.7	33 9
	Sodium bromide	20.0 lbs. Bromine	361	24.2	35.4

[1] 1600 pounds of 6-9-15 applied in each case.
[2] Each figure for this field is the average of 5 replicates, each 29 feet long, from a Latin Square. Minimum difference in yield required for significance is 53 bushels for field #1 and 50 bushels for field #3.
[3] The figures on yield on this field are the averages of 8 replicates each 50 feet long, from a Latin Square. Those on stem-end browning and net necrosis are the averages of 5 one-bushel samples taken from 5 blocks of the Latin Square. The minimum difference in yield required for significance is 32 bushels.

appeared to cause a reduction in the amount of net necrosis in 1943. Replanting of the tubers showed that this reduction was largely due to less spread of leafroll to those particular plots. In view of the failure of this element to affect the amount of net necrosis in 1944, either in sprays or in the fertilizer, it seems likely that the reduction in 1943 was due to unequal spread of leafroll and that chromium has no effect on the amount of net necrosis or on the spread of leafroll virus.

Although small plots with only a few replications were used in most cases, the data provide some information on the effect of the compounds used on yield. Of the several compounds applied as sprays, 0.2 per cent potassium iodide was quite toxic causing injury to the foliage and a highly significant decrease in yield. The same concentration of cadmium chloride caused some injury to the foliage but the reduction in yield was not statistically significant. The same compound when added to the fertilizer (20 pounds per

acre) was not toxic. Cobalt chloride added to the fertilizer at a rate of 5 pounds of cobalt per acre, caused a severe stunting of the plants and a highly significant depression of yield. Sodium vanadate also caused a reduction in yield when applied at the rate to give 2 pounds of vanadium per acre. Copper chloride caused reduced yields when applied at the rate of 50 to 100 pounds per acre.

The other compounds were not particularly toxic at the rates or concentrations used. On the other hand, strontium chloride when added to the fertilizer in 1942 gave an increase in yield just short of statistical significance and when applied as a spray in 1943 it caused a statistically significant increase in yield. No response from this compound was obtained in 1944. While the data are not conclusive they do suggest that strontium salts may possibly stimulate yield some seasons or on some fields.

Minor Elements Mixtures. Milorganite[3], and Es-Min-El[4], two commercial fertilizer materials reported to contain several minor elements, were tested in 1944 (Table 29). Milorganite also contains N, P, and K, therefore, in making up the fertilizer mixture, a 6-9-15 commercial fertilizer, KCl and superphosphate were mixed with the milorganite in proportions sufficient to make the total application equivalent to the control (1600 pounds of 6-9-15). Applications of both milorganite and Es-Min-El were without an effect on the amounts of either net necrosis or stem-end browning. Neither product caused an increase in yield. In fact, the data suggest that Es-Min-El in the larger amount used may be slightly toxic. Mixture #1 was compounded to contain miscellaneous elements in small amounts not otherwise tested. In the amounts used the mixture did not affect the amount of net necrosis or stem-end browning produced nor did it noticeably affect the yield.

Mercury Salts. Bonde and Schaal (1) reported that the addition of mercury salts to potato fertilizer reduced infection of tubers by certain microorganisms. In view of the uncertainty of the cause of stem-end browning, the effect of such salts on the incidence of this disease was determined. Table 30 lists the salts

[3] A product of the Milwaukee Sewage Disposal Plant. For analysis see report by Rehling and Truog (13).

[4] Reported to contain manganese, zinc, copper, iron, magnesium, boron, and cobalt. The authors are indebted to the Tennessee Corporation for supplying this product.

TABLE 29

The Effect of Adding Minor Element Mixtures to Potato Fertilizer on Yield, Stem-end Browning, and Net Necrosis

Field number and year	Treatment[1]	Yield	Stem-end browning	Net necrosis
2[3]	Control	379	56.6	26.9
1944	Mixture 1[3]	336	52.7	26.5
	Milorganite[4]	360	55.5	31.4
3[5]	Control	413	20.1	42 2
1944	50 lbs./A. Es-Min-El	400	16.3	55 2
	100 lbs./A. Es-Min-El	381	19.0	42.5

[1] 1600 pounds of a 6-9-15 commercial fertilizer applied per acre on all plots.
[2] The figures on yield for this field are the average of 5 replicates, each 29 feet long, from a 5 x 5 Latin Square. Minimum difference on yield required for significance is 53 bushels.
[3] Mixture 1 contained the following:

Compound	Rate of Application
$Y(NO_3)_3 \cdot 4H_2O$	1 lb. yttrium per acre
$La(NO_3)_3 \cdot 6H_2O$	1 lb. lanthanum per acre
$Ce(NO_3)_3 \cdot 6H_2O$	1 lb. cerium per acre
$Nd(NO_3)_3 \cdot 6H_2O$	0.8 lb. neodynium per acre
$Th(NO_3)_4 \cdot 4H_2O$	1 lb. thorium per acre
$UO_2(NO_3)_2 \cdot 6H_2O$	1 lb. uranium per acre
$RbCsCl_2$	0.42 lb. rubidium and 0.66 lb. cesium per acre.

[4] Milorganite applied at the rate of 1000 pounds per acre. 6-9-15, KCl, and superphosphate were added to make the total applications equivalent to 1600 pounds of 6-9-15.
[5] The figures on yield are the averages of 8 replicates, each 50 feet long in an 8 x 8 Latin Square design. Those on net necrosis and stem-end browning are the averages of 5 replicates each of about 160 tubers, from 5 blocks of the Latin Square. Difference in yield required for significance was 32 bushels

used, the rates of application and the results. Of the several types of compounds used, calomel was the most effective in reducing the amount of stem-end browning and in no case did moderate amounts significantly decrease the yield. Increasing the rate of application above 5 or 10 pounds of calomel per acre did not cause further decreases in stem-end browning. The failure of the mercury salts to eliminate the disease even where toxic amounts were added and the fact that relatively insoluble calomel was the most effective, make it appear that mercury salts function other than as a nutrient. The failure of larger amounts to further decrease the incidence of disease indicates that the effect of mercury was not one of rendering insoluble soil constituents that might effect stem-end browning.

It was thought possible that calomel was acting as a fungicide. Consequently, other fungicides were added to potato fertilizer. Fifteen pounds per acre of Arasan, Cuprocide or Semesan, were

TABLE 30

Effect of Mercury Salts on Yield, Stem-end Browning, and Net Necrosis

Field No. and year	Seed[1]	Compound added	Rate per acre		Yield per acre	Stem-end browning	Net necrosis
			Cmp'd	Hg			
			lb.	lb.	Bu.	%	%
1[2] 1943	Keswick	Control	—	0	380	44.8	12.2
		Calomel	5.00	4.25	352	15.6	14.6
		Mercuric chloride	2.87	2.12	302	34.0	20.5
		Mercuric chloride	5.74	4.25	286	23.2	16.7
		Yellow mercuric oxide	4.57	4.25	294	27.8	21.8
2[3] 1944	Keswick	Control	—	0	365	43.8	35.3
		Calomel	5	4.25	358	25.4	35.3
		HgCl-Hg-Cl_2[5]	5	4.07	358	37.3	40.6
		Mercurous sulfate	5	4.03	347	50.3	38.0
		Hg-Zn Amalgam	5		348	35.9	32.8
3[4] 1944	Keswick	Control	—	0	349	46.9	30.1
		Calomel	5	4.25	341	34.4	35.8
		Calomel	10	8.50	336	39.2	36.7
		Calomel	15	12.75	332	36.8	38.0
		Calomel	25	21.25	342	34.8	32.7
	Minnesota	Control	—	0	3[illegible]8	17.4	30.8
		Calomel	5	4.25	315	10.1	34.5
		Calomel	10	8.50	321	5.7	32.5
		Calomel	15	12.75	300	6.1	27.5
		Calomel	25	21.75	290	5.9	27.6

[1] The Keswick strain is quite subject to the development of stem-end browning. The Minnesota lot is much less so.
[2] The figures for this field are the averages of 5 replicates, each 29 feet long, from a 5 x 5 Latin Square. Minimum difference in yield required for significance is 60 bushels per acre.
[3] The figures for this field are the averages of 6 single row plots, each 29 feet long in a 6 x 6 Latin Square design. Minimum difference in yield required for significance is 23 bushels per acre.
[4] The figures for this field are the averages of 6 single row plots, each 29 feet long in a double-row Latin Square design. The minimum difference in yield required for significance is 22 bushels per acre.
[5] Two parts calomel and 1 part mercuric chloride.

without effect, as were Thiosan (up to 30 pounds per acre) and Spergon (up to 50 pounds per acre).

It seems more likely that calomel acted indirectly in that it affected the physiology of the potato plant. Bonde and Schaal (1) reported that the mercury salts stunted the plants early in the growing season and the plants apparently recovered later in the season. That this type of effect may be an explanation for the action of calomel on stem-end browning is suggested by the data in Table 31. Treated and untreated samples were dug at different stages of maturity. The effect of calomel was most noticeable in the early dug samples. It had disappeared at the last digging. The data in Table 31 also show that the date of digging influences the amount

of stem-end browning in the control. Hence, if the mercury salts alter the physiological maturity of the plant it would be expected to affect the amount of stem-end browning.

TABLE 31

The Effect of Calomel in Potato Fertilizer on Yield, Net Necrosis and Stem-end Browning in Tubers Dug at Different Dates

Digging date[1]	Treatment[2]	Yield[3] per acre	Stem-end browning[3]	Net necrosis[3]
		bu.	%	%
August 26, 1944	No calomel	143	34.1	1.3
	5 lbs. calomel per acre	142	23.1	2.3
September 9, 1944	No calomel	280	21.4	7.2
	5 lbs. calomel per acre	230	10.8	9.6
September 27, 1944	No calomel	339	11.8	13.0
	5 lbs. calomel per acre	326	13.9	18.0

[1] Tops pulled and moved from field 1 or 2 days before potatoes were dug.
[2] All plots received 1600 pounds per acre of a 6-9-15 commercial fertilizer.
[3] Average of 6 single row plots, each 29 feet long, in a 6 x 6 Latin Square design.

DISCUSSION

The fact that plots fertilized with chemically pure salts as well as those plots located on land not previously fertilized produced crops containing appreciable amounts of stem-end browning and net necrosis is proof that the general fertilizer practices in Aroostook County are not, in themselves, directly responsible for these two diseases. It is true that fertilizer practices may have increased the importance of these diseases but it is equally certain that they cannot be held responsible for the existence of such diseases.

The data from the permanent plots provide strong evidence that the continued use of fertilizers high in chloride creates a condition that may result in a high incidence of stem-end browning and net necrosis in the stored crop. The similarity of the data obtained on plots fertilized with ordinary commercial grade fertilizer with potassium sulfate substituted for muriate of potassium as source of potash with those from the so-called "C.P." plots is evidence that chloride is the principal if not the only extraneous material in commercial fertilizers that affects the amount of these

two diseases. The term extraneous refers to material other than N, P, and K. If this inference is correct it follows that the data on the effect of phosphate applications on the incidence of net necrosis and leafroll spread can be interpreted as an effect of phosphorus itself.

The role that potassium plays in relation to stem-end browning is not so clear. Certain of the data do indicate that potassium has an effect on this disease. These are supported by analytical data on tubers from the 1942 and 1943 crops made by Robinson and Edgington.[5] In the case of tubers from plots fertilized with mixtures containing chloride there was a direct correlation between the amount of chloride in the tubers and the incidence of stem-end browning. There were very few exceptions. However, these same samples gave an equally good correlation between potassium content and stem-end browning. Samples from plots fertilized with chemically pure salts or with mixtures containing potassium sulfate were higher in stem-end browning than were samples with a similar or even higher chloride content from the unfertilized plots or from those plots receiving 4-8-0 or 4-8-4 mixtures. The samples from the former type of plots were considerably higher in potassium than those from the latter type. In fact, the stem-end browning content of all samples appeared to be more definitely correlated with the amounts of both chloride and potassium present rather than to that of either singly.

It seems probable that the amount of chloride and potassium in the tuber is but one of several conditions that may result in stem-end browning. At present there is no explanation for the failure of all tubers containing large amounts of these elements to develop the disease or the fact that some tubers low in chloride and in potassium develop the disease. Hence these elements must be regarded as contributory rather than as causal.

It is probable that the continued use of fertilizers high in chloride tends to promote leaching of other soil constituents since most chlorides are soluble and the bulk of the applied chloride is not removed by cropping. Unfortunately analysis of the soil

[5] Personal communications from W. O. Robinson and Glen Edgington, Division of Soils, Fertilizers, and Irrigation, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, Beltsville, Maryland.

samples is not yet completed. It seems unlikely that extensive leaching of any minor element or elements can account for the results obtained. If such were the case it would be necessary to assume that the deficiency exists in virgin soil, that continued cropping (with chemically pure salts as fertilizer) does not magnify the deficiency, and that a change from a fertilizer high in chloride to one low in this element helps to rectify the condition.

The effect of fertilizer practice on the spread of leafroll virus, with respect to the effect of both chloride and phosphorus, cannot be explained on the basis of present information. It would seem that the effect must be either on susceptibility of the plant to leafroll virus or to an effect on aphid population. Aphid counts on the permanent plots failed to establish any relationship between the amount and kind of fertilizer used and aphid population. The effect of these elements on the spread of leafroll virus does not appear to be due to their effect on physiological maturity, or more specifically, on the time at which the plants die down in the fall. If this were true, nitrogen and potash would be expected to be of more importance than phosphorus, for deficiencies of these elements tend to hasten maturity while a deficiency of phosphorus tends to prolong it. Furthermore, at least in some seasons, plants on the C.P. plots stay green longer than those on other plots (4). As the greatest leafroll spread occurs late in the season, such plots would normally be expected to show a higher percentage of leafroll, but this is not the case.

RECOMMENDATIONS

The data herein presented suggest a method by which the prevalence of these two diseases can be reduced. First, avoiding the use of amounts of phosphate and potash in excess of those required for maximum yields should tend to reduce the amounts of stem-end browning, net necrosis, and leafroll in the crop. Recent experiments have shown that the amount of phosphate commonly used in Maine can be reduced without a decrease in yield and that on some fields the amount of potash applied may be reduced to 200 pounds per acre or less without causing reductions in yield (4, 5, 11). Second, a reduction in the amount of chloride in the fertilizer would be beneficial. This may be accom-

plished by substituting potassium sulfate, potassium nitrate or potassium metaphosphate for the muriate of potash (potassium chloride) usually used as source of potash. It should be kept in mind that these suggested changes in fertilizer practice might not give immediate results but within a few years the crop produced would be less subject to the development of stem-end browning and net necrosis than if no changes were made.

SUMMARY

The incidence of stem-end browning and of net necrosis in the stored potatoes from a series of permanent soil fertility plots was markedly affected by fertilizer practice. The amount of stem-end browning in the crop was positively correlated with the amount of chloride and potassium applied in the fertilizer and that of net necrosis to the amount of phosphorus and chloride. These factors are contributory rather than causal. Other fertilizer constituents had little or no effect. The effect of a given treatment was most apparent on plots that had received that treatment for a period of years. The amount of stem-end browning or of net necrosis that developed in the stored crop from other than the permanent plots was not always affected by a change in treatment the year the change was made, but continued use of the new treatment generally resulted in a progressive change in disease incidence.

The tendency of plots receiving fertilizer mixtures high in phosphorus to produce a crop with a high percentage of tubers affected with net necrosis was found to be due primarily to a greater spread of leafroll virus on such plots. In the case of plots receiving mixtures with a high chloride content, high net necrosis percentages were not only due to a greater spread of leafroll virus but also to a greater tendency of leafroll tubers from such plots to develop net necrosis.

Other fertilizer practices were of less importance. Liming to the point of the appearance of scab or turning under organic matter increased the incidence of stem-end browning in the crop but not that of net necrosis. Tubers from the 3-year rotation plots developed approximately the same amount of stem-end browning or of net necrosis as did those from the 2-year rotation plots and those plots planted to potatoes every year. The amount of nitrogen,

the source of nitrogen, the amount of phosphorus or the equivalent acidity of the fertilizer mixture were all without appreciable effect on the incidence of stem-end browning in the crop. Except for the amount of phosphorus, these were also without effect on the development of net necrosis.

The addition of boron to potato fertilizer, in amounts below the toxic range, had no effect on the development of stem-end browning or of net necrosis in the stored crop. The use of amounts of borax in excess of five pounds per acre sometimes resulted in a decrease in the amount of stem-end browning but such decreases were accompanied by appreciable decreases in yield. Application of borax by spray to potato plants was also without effect on the amount of stem-end browning and net necrosis that developed. The data presented also indicate that the following minor elements are without any appreciable effect on the incidence of these two defects: barium, bismuth, bromine, cadmium, chromium, cobalt, fluorine, iodine, lithium, manganese, strontium, vanadium, and zinc. The amounts applied were between 2 and 20 pounds per acre. In small amounts (approximately 1 pound per acre), cerium, cesium, lanthanum, neodynium, rhubidium, thorium, uranium, and yttrium were likewise without effect. A 0.2 per cent potassium iodide spray, or cobalt added to the fertilizer at a rate of two pounds per acre, was found to depress yields. The data indicate that in some years applications of strontium salts may result in increased yield. The addition of mercury salts, especially calomel, to potato fertilizers at the rate of 5 pounds per acre, reduced the amount of stem-end browning in the crop. It is thought that this effect is due to the effect of mercury on the physiological maturity of the potato plant.

Recommendations include the use of fertilizers low in chloride and a reduction in the amount of phosphorus and potash applied where such reductions can be made without yield reductions.

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